Demand for Complementary Financial and Technological Tools for Managing Drought Risk: Evidence from Rice Farmers in Bangladesh

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Abstract. Financial and technological innovations that mitigate weather-related production risks have the potential to greatly benefit farmers in many risk-prone. In this study we examine farmers' preferences for two distinct tools that allow them to manage drought risk: weather index insurance and a recently released drought-tolerant rice variety. We illustrate how these tools can independently address drought risk and demonstrate the additional benefits gained by combining them into a complementary risk management product. Findings indicate that farmers are generally unwilling to adopt the drought-tolerant variety independent of insurance, largely due to a yield penalty under non-drought conditions. When bundled with insurance, however, farmers' valuation of the variety increases. Farmers value insurance on its own, but even more so when bundled with the drought-tolerant variety. The results provide evidence that farmers value the complementarities inherent in a well-calibrated bundle of risk management tools.

Keywords: risk management, insurance, drought-tolerant rice, discrete choice experiments, Bangladesh

JEL codes: D12, Q12, Q14, Q16, Q54

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1. Introduction

In much of the developing world, agricultural production entails a great deal of risk. While there are many sources of risk, perhaps the most serious are weather-related hazards such as droughts, floods, and storms. In rice-producing areas of Asia, droughts have been identified as a particularly serious constraint to rice production (Huke and Huke 1997; Pandey, Bhandari, and Hardy 2007). When droughts occur, rice production suffers significant negative impacts both in terms of a decrease in cultivated area as well as a decrease in yields. The magnitudes of these effects depend crucially on both the timing and intensity of the drought. Delayed onset of the seasonal monsoon, for example, often results in delayed transplanting of the monsoon season rice crop which may, in turn, translate into a reduction in area under rice production. Additionally, like most crops, rice is sensitive to moisture deficits around the flowering stages, and droughts during these critical stages of crop growth can lead to spikelet sterility or a reduced number of spikelets, potentially resulting in severe yield losses. Droughts at other stages of the growth cycle can result in declines in leaf area, reduced photosynthesis due to closure of the stomata, reduced plant height, or changes in assimilate partitioning (i.e., growth of deeper roots seeking out moisture deeper in the substrate, often at the expense of the shoot), which also have yield implications (Bouman et al. 2007). These effects may be particularly pronounced where there is little infrastructure (for example, surface or groundwater irrigation) that allows farmers to exercise some control over the effects of weather by supplementing deficient rainfall with other sources of water.

Contrary to conventional wisdom, it is not only arid areas that face drought risk. Even in areas that typically receive adequate rainfall, underlying climate variability entails an implicit risk of drought. Bangladesh, for example, is not typically thought of as particularly susceptible to droughts. Rather, with its subtropical monsoon climate, alluvial floodplains and the fertile Ganges-Brahmaputra river delta, Bangladesh is most often associated with floods and cyclones. Yet Bangladesh contains over 5 million hectares of drought-prone areas, mainly located in the country's northwestern and northern regions.

To be sure, Bangladesh's exposure to weather risk is expected to increase as a result of climate change, making it one of the most affected developing countries (Nelson 2009). While global circulation models typically predict an overall increase in monsoon precipitation in Bangladesh, such models also typically predict an increase in monsoon *variability*, leaving farmers particularly vulnerable to extreme precipitation events—including both droughts and floods. For example, Rahman et al. (2007) predict increasing drought intensity in Bangladesh using two alternative climate change scenarios, with the area susceptible to severe droughts increasing four-fold.

At present, major countrywide droughts occur roughly every 5 years, though more localized droughts occur with greater frequency (Ramamasy and Baas 2007). Since independence in 1971, Bangladesh has experienced 11 severe droughts (DCRMA 2013). These droughts have had widespread impacts, affecting on average 47 percent of total area and 53 percent of the population (Bangladesh, Ministry of Food and Disaster Management 2010; WARPO 2005). It is estimated that each year, droughts affect over 2 million hectares of the monsoon season transplanted *aman* rice crop, and during very severe droughts, *aman* rice yields can be reduced by as much as 45-60 percent (Ramamasy and Baas 2007).

In addition to the obvious effects on rice production, there are other impacts that directly result from droughts. In much the same fashion that droughts affect rice production, droughts can also affect the production of other crops such as jute, pulses, oilseeds, and vegetables which are often cultivated to provide smallholder farm households with either diversified farm incomes or vital sources of nutrition. Furthermore, droughts can affect the growth of fodder crops and grasses, which reduces the volume of foodstuff available for feeding domesticated livestock. In addition, droughts during the hot summer months can increase the risk of heat stroke and diseases amongst livestock and poultry populations. Prolonged dry spells during the hot summer months can also lead to drying up of rivers and ponds, which can reduce aquaculture production; an important component of agricultural production in Bangladesh. In sum, the occurrence of a drought imposes significant strains on smallholder farmers' livelihoods, and evidence suggests that these effects can persist for many years (Dercon 2004), often resulting in food insecurity and economic instability. To cope with these stresses, farmers may resort to depleting savings or other assets stocks in an attempt to smooth consumption, potentially limiting their ability to cope with drought stress in the future.

There is evidence to suggest, however, that these effects may not be the most pressing risk burdens that households face. Lybbert and Carter (2014, p. 403) note that, "the *threat* of drought, like a bully, induces households to opt out of higher return livelihoods and store their assets in forms that have low or negative returns but high liquidity" (emphasis added; see also Pandey et al. 2007). Therefore, there is an important distinction to be made between this type of ex ante risk and the more obvious ex post risks of production losses and asset depletion. The ex ante burden induces an inherently behavioral response, where precautionary actions are taken in anticipation of a shock, while the ex post burden induces what might be conceptualized as a more economic response, resulting in the depletion of human, physical or social capital after a negative shock (Dercon, 2004). By inducing these sorts of precautionary behaviors, ex ante risk affects the household's long-term growth trajectory, which further inhibits the households' ability to accumulate asset stocks that can be used in ex post responses against these shocks in the future. While these effects are widely acknowledged, only recently has there been an attempt to quantify the relative effects of ex ante and ex post risk burdens on household welfare. Elbers et al. (2007) analyze the effects of ex ante and ex post risk on capital accumulation (specifically livestock) by simulating a large number of hypothetical growth paths 50 years into the future using panel data from Zimbabwe. While their finding of a large effect of risk on capital accumulation is not surprising, their finding that the risk effect is dominated by the ex ante risk effect draws attention to this distinction. Even in the absence of an ex post risk burden (i.e., the actual losses to households' livestock holdings), the ex ante risk burden results in long-run capital accumulation 46 percent lower than under a risk-free scenario. These ex ante risk burdens lower the household long-term growth trajectory, trapping them in a vicious cycle of poverty (Barnett et al. 2008).

In the absence of formal means to manage these risks, households often rely on informal risk-coping mechanisms such as informal savings, gifts, and loans (Alderman and Paxson 1992; Dercon 1996; Fafchamps and Lund 2003; Dercon et al. 2006; Clarke, Das et al. 2012). Santos et al. (2011) have questioned the effectiveness of such mechanisms, highlighting the need for more formal mechanisms to reduce ex ante risks to households. But this is no trivial matter. It essentially implies the need to correct market failures that are caused by complex geographic and institutional factors contexts, especially in rural parts of many developing countries. Many attempts to address these market failures and provide formal risk management products in developing countries have proven unsuccessful, not in some small part due to prohibitively low demand. Yet these persistent market failures result in large numbers of farmers perpetually exposed to drought risks. Hence, there may be a need to continually explore innovative and inexpensive strategies to manage risks that pose significant threats to farmers' livelihoods.

In this study, we consider two strategies aimed at helping farmers manage risks associated with drought. One, a drought-tolerant (DT) rice variety, is a technological innovation that reduces the impact of drought stress on agricultural production, thereby partially insulating an important component of farmer livelihoods from the negative impacts of droughts. The other, a weather index insurance (WII) product, is a financial innovation that allows farmers to transfer a portion of their risk to the insurer (for a price), who pays indemnities in the event that certain levels of drought stress occur. While both tools address drought risk, they do so in very different and imperfect fashions. Despite these imperfections, we argue that they can be combined to form a fairly comprehensive and complementary risk management tool.

This paper makes several important contributions to the literature on risk management solutions for developing-country agriculture. First, building on the work of Lybbert and Carter (2014), we illustrate how a drought index insurance policy can be calibrated to complement the performance of the drought-tolerant rice variety, such that the bundled product addresses the individual weaknesses of the two instruments in isolation. In so doing, we demonstrate how bundling the DT rice variety with the insurance provides an implicit subsidy on the cost of insurance, further incentivizing insurance uptake in a manner that improves the financial viability of insurance provision. Additionally, using a discrete choice experiment, we explore farmers' preferences for each of these tools independently as well as in a complementary bundle. This approach provides valuable insight into farmers' perceptions of these various risk management tools, and informs the feasibility of promoting such a risk management tool, at least in the context of northwestern Bangladesh.

2. Technological and Financial Tools for Managing Drought Risks

Drought-Tolerant Rice

Over the last several years, there has been a great deal of interest in the development of stress-tolerant varieties for major field crops. Given the importance of rice as a source of caloric intake and farm income for millions of farmers across Asia and Africa and the increasing risks posed by short-term climate variability and long-term climate change, the development of abiotic stress-tolerant rice is a particularly important area of research. To date, efforts to develop abiotic stress tolerance in rice have focused on salinity tolerance, submergence tolerance, drought tolerance, as well as several other traits. An important driving force behind this research has been the Stress-Tolerant Rice for Africa and South Asia (STRASA) project, a collaborative research program involving the International Rice Research Institute (IRRI), the Africa Rice Center, and national research systems across the two continents. In 2011, the Bangladesh Rice Research Institute (BRRI), with technical support from IRRI, released BRRI dhan 56 (with genomic line number IR 74371-70-1-1), a drought-tolerant (DT) rice variety suitable for cultivation in rainfed areas in Bangladesh during the *aman* (summer monsoon) season. BRRI dhan 56 is a short-duration variety, maturing in roughly 105–110 days.[1] This short duration provides a means of escaping either early or late season droughts, such as those arising from either late monsoon onset or early monsoon cessation. In addition to providing a means of escaping droughts, the short duration also offers farmers an opportunity to harvest their *aman* rice crop at full maturity relatively early, thereby providing more time to prepare land for the winter crop.[2] Unlike other short-duration varieties, however, BRRI dhan 56 can tolerate extended periods of dehydration—even in excess of three weeks without rain—with yields that exceed those of other common *aman* varieties. BRRI dhan 56 can withstand periods of 14–21 days without rain during reproductive stages (for example, panicle initiation and flowering) without reductions in yields, and experiences only slight reductions in yields for dry spells of three to four weeks if there is sufficient soil moisture. Studies based on experimental field trials suggest that BRRI dhan 56 provides a yield advantage of 0.5 tons per hectare (t ha^{-1}) under moderate drought stress conditions and 0.8 to 1.0 t ha^{-1} under severe drought conditions.[3]

There are several important shortcomings of BRRI dhan 56 (and other drought-tolerant varieties) that make them imperfect solutions to address problems of drought risk. First, the principal benefits are *relative*, rather than *absolute*. In other words, while BRRI dhan 56 may confer

[1] For comparison purposes, BR 11, the most widely cultivated *aman* variety, has a duration of 145 days.

[2] Typically, the dry season crop is either *Boro* rice or *rabi* wheat. In some cases, farmers have taken advantage of short-duration *Aman* varieties to harvest early, plant a short-duration horticulture crop (for example, potatoes), and still have time to prepare their land for the *Boro* or *rabi* crop.

[3] These results were based on field trials conducted in India, and the stated yield advantages are relative to IR 36 and IR 64, two popular megavarieties cultivated in eastern India. To our knowledge, no studies have compared the performance of BRRI dhan 56 to other commonly grown *Aman* varieties under drought conditions in Bangladesh.

benefits *relative to* other varieties under moderate and even severe droughts, this still implies *absolute* yield declines under drought stress conditions. In the case of BRRI dhan 56, yields under moderate and severe drought are, respectively, roughly 40 and 70 percent lower than yields under well-irrigated conditions. So even though BRRI dhan 56 may perform better than other varieties under drought stress, farmers cultivating BRRI dhan 56 are still at risk of rather significant losses in rice production and farm incomes during droughts.

Additionally, since the benefits of BRRI dhan 56 may only be observed during periods of drought, and since droughts do not occur every year, the benefits of BRRI dhan 56 will not be observed every year. These stochastic relative benefit streams led Lybbert and Bell (2010) to observe that, in many ways, the DT trait operates in a fashion similar to insurance. By paying a higher price for the additional yield under drought stress, farmers are essentially paying a premium. And as with insurance, this premium may "pay out" in years in which the farmer experiences drought, but may be viewed as a lost payment in years when there is no drought and during which the benefits of the DT variety vis-à-vis the non-DT variety are not realized. Unlike insurance, however, the "terms" of the insurance are concealed from the farmer, muting any spillover benefits.

Furthermore, there is likely some degree of drought stress (call it extreme drought stress) at which the yields of BRRI dhan 56 may be no better than those of other common *aman* varieties. Thus, while BRRI dhan 56 may confer benefits relative to other *aman* varieties during drought, the benefits are non-monotonic in nature, positive and increasing initially during moderate drought stress, positive but decreasing under severe drought stress, and non-existent under some extreme drought stress level. This is consistent with Lybbert and Bell's (2010) illustration of the challenges posed by drought-tolerant varieties in a more general context. Thus while DT elicits a great deal of excitement from its proponents, there are several key factors which may inhibit the widespread adoption of DT and may limit its ability to help farmers adequately mitigate drought risk.

Weather Index Insurance

While micro-credit and micro-savings have been widely used in Bangladesh, traditional crop insurance has seen limited success in the country, consistent with experiences from other developing (and many developed) countries (Hazell 1992; Skees, Hazell, and Miranda 1999; Smith and Watts 2009). Traditional crop insurance has many well-known problems (Hazell et al. 1986; Binswanger 2012). First, the costs associated with monitoring and assessing losses lead to high administrative loads, often leading to insurance premia in excess of most farmers' willingness-to-pay. Additionally, there are vast informational asymmetries between the insured and the insurers that may result in adverse selection and moral hazard, problems that are particularly pronounced in rural areas in developing countries. Furthermore, many of the risks that traditional crop insurance policies address are highly covariate. This increases the insurer's value-at-risk, and since this additional value-at-risk would generally require a great deal of context knowledge to fully understand, this would have significant implications for the availability and cost of reinsurance. Finally, for traditional crop insurance programs in developing countries, there is often a mismatch between insurance demand and the insurance benefits. Cole et al. (2008), Giné et al. (2008), and Giné and Yang (2009) find that insurance uptake is positively correlated with wealth, arguing that credit and liquidity constraints make it infeasible for poorer farmers to purchase insurance, especially since insurance must be purchased at the beginning of the growing season, a period of time during which scarce financial resources must generally be allocated to the purchase of other agricultural inputs. Wealthy farmers who could afford the insurance can typically either self-insure or have access to other informal risk management mechanisms at a lower cost than crop insurance. Poorer farmers—who would likely greatly benefit from such risk management—are typically too poor or credit constrained to take advantage of crop insurance.

Weather index insurance (WII) is viewed by many as an alternative to traditional crop insurance, particularly for rural households in developing countries that cannot afford or do not have access to other financial instruments to help them cope with weather-related shocks that threaten livelihoods (Skees 2008). Index-based insurance products have several advantages over traditional crop insurance. First, indemnity payments are based on index triggers that are typically easy to observe and measure, making the index more transparent to the insured, minimizing asymmetric information between the insured and insurer, and reducing the probability of adverse selection and moral hazard (Clarke, Das, et al. 2012; Clarke, Mahul, et al. 2012; Ruck 1999; Ibarra and Skees 2007). This allows for indemnities to be calculated easily and potentially distributed in a timely manner (Turvey 2002). Additionally, because indemnity payments are based on an index rather than loss adjustments calculated for each farm that is insured, operating costs may be significantly lower than those of other types of agricultural insurance. Along the same lines, contracts can be standardized and need not be tailored to the individual needs of different policyholders (Skees 2008). Furthermore, there is no need for individual field loss assessments, since the indemnity payments are tied to index triggers rather than actual losses, which significantly reduces providers' administrative costs (Barnett, Barrett, and Skees 2008). Finally, because the index triggers are independently measured and easily verifiable, local context knowledge becomes relatively unimportant, so it is easier for reinsurers to understand risks (Alderman and Haque 2007).

Despite these benefits, most pilot index insurance programs have met with limited success in three areas (Skees 2010): (1) a relatively small portion of the potential insured farmers take up the insurance; (2) those that do purchase relatively little coverage; and (3) poor farmers are usually not among the insured, even though they would likely benefit the most from insurance. There are several potential explanations for this low observed demand. de Janvry et al. (2014) identified two factors that may contribute to low demand, especially when these policies are marketed directly to individuals in settings where formal insurance merely complements existing informal risk-sharing mechanisms. First, insurance decisions at the individual level may generate positive externalities (specifically, reducing the risks associated with the distribution of aggregate wealth among network members) that may induce free-riding behavior among the non-insured members of the group. Second, if a group member anticipates that other members in the group will not take up insurance, insurance may actually have a negative value, and the decision maker will almost certainly opt out of insurance. Perhaps the primary reason for these apparent failures can be attributed to basis risk, or the potential mismatch between the index trigger and actual on-farm losses (Miranda 1991). Because indemnity payments are based on index measurements, which in turn are often based on weather measurements from geographically displaced weather stations, there is a nontrivial probability that the insured will not be indemnified even if they experience losses. The success and scalability of an index insurance program depends crucially on addressing the issue of basis risk.[4]

[4] Dercon et al. (2014) have suggested that one method for addressing basis risk is to market insurance products to groups rather than individuals. They show that, under the assumption that informal risk sharing is exogenously determined and constrained by limited commitment on the part of agents, increased access to risk sharing mechanisms actually increases demand

In order to add the most value to policyholders and reduce basis risk, index insurance products need to be 'intelligently designed', such that the variables on which the index is based should be highly correlated with farm incomes (Carter 2009). A naïve reading of this may suggest that design is a relatively simple matter. However, the reality is far more complex given evidence suggesting relatively low correlations between yields and many weather variables on which most index-based insurance products are based (Rosenzweig and Binswanger 1993). Smith and Watts (2009) review a series of studies examining the correlation between rainfall and crop yields, and show that the average correlation is only 0.6, suggesting that nearly half of the variation in yields is explained by factors other than rainfall.

Some proponents suggest the use of normalized difference vegetation indices (NDVI), but correlations between NDVI and yields rarely fare better than rainfall. Additionally, anecdotal evidence also suggests that farmers (especially those in developing countries) tend to prefer an index that they can directly observe. Satisfying these dual objectives of transparency and high correlation with farm profits is a difficult endeavor, and unfortunately has resulted in some poorly designed products across several different contexts.

3. Potential Bundles of Drought-Tolerant Rice Varieties with Weather Index Insurance

Taken separately, neither improved varieties nor index insurance is a perfect solution to the problem of covariate weather shocks. DT crops yield stochastic and non-monotonic benefit streams, and the benefits are largely relative rather than absolute. WII, on the other hand, suffers from problems of basis risk and, as a result, most index insurance products have thus far been prone to low demand. The individual shortcomings of technological and financial risk management tools offer researchers, practitioners, and policymakers with unique opportunities to learn about the potential interactions between these two tools. Including the two products in a bundled risk management product allows for the product to take advantage of the strengths of each of these tools, allowing for some interesting complementarities (Lybbert and Carter 2014). A bundled DT-WII product, for example, could provide monotonically increasing (or at least

for index insurance. The potential success of such an approach rests critically on the extent to which basis risk is correlated among group members: if basis risk is largely idiosyncratic, then informal risk sharing may complement index insurance. Based on training experiments conducted in Ethiopia, they found increased interest in weather index insurance products among risk-sharing groups whose leaders received training on the policies and payouts and subsequently encouraged their group members to attend trainings.

non-decreasing) benefits, since the insurance component would still provide benefits beyond the drought stress level at which the relative benefits of the DT variety begin to decline. Additionally, because the DT variety maintains higher yields than many other varieties under drought stress, the resulting loss in farm incomes during drought is less than it otherwise would be, implying a smaller amount of farm income at risk due to drought. This has obvious implications for insurance coverage: if less farm income is at risk, or if losses have a lower probability of occurrence, then insurance against these farm income losses should be less expensive.

In this section, we describe how we constructed a DT-WII product for our study area in Bogra district, Rajshahi Division, in northwestern Bangladesh. As a starting point, we refer to Lybbert and Carter (2014), who helpfully demonstrate how a DT-WII product might be structured. While an independent, "full coverage" index insurance product could be structured to pay indemnities during moderate, severe, and extreme droughts, if the insurance were bundled with the DT, a cheaper "limited coverage" WII policy could be structured to pay out only under severe and extreme droughts. This structure takes advantage of the positive and increasing relative benefits that the DT confers during moderate drought, while providing indemnities under severe droughts that compensate farmers for the declining relative benefits of the DT under severe droughts.

Some important issues surround the bundling of a DT-WII package. First, the bundle's two components have significantly different benefit profiles. Insurance indemnity payments and triggers can be easily and inexpensively modified, but the benefits conferred by DT technologies can only be modified with additional investments in research and development—efforts that may require up to 10-12 years to develop a new variety through conventional breeding efforts (Hossain and Abedin 2004). It is therefore easier to modify an insurance contract to complement the DT rice than vice versa. But before calibrating a complementary insurance product, one must have a fairly comprehensive understanding of the yield profile of the DT variety, which is subject to a great deal of variability attributable, for instance, to agrecological conditions under which the variety is grown and farmers' input use decisions and crop management practices.

Furthermore, it is not necessarily a simple and straightforward matter to calibrate the WII to perfectly complement the DT rice. Calibrating a limited-coverage index insurance policy to complement DT requires consideration of three important aspects: index construction (including triggers), indemnity payments, and pricing. Properly constructing the index for a complementary limited-coverage product requires comprehensive knowledge of the performance parameters of the DT variety. In our case, we require detailed information on the performance of BRRI dhan 56. Unfortunately, given its relatively novelty and lack of farmer experience cultivating BRRI dhan 56 under a wide range of weather conditions, such detailed information is not yet available. What information is available is relatively limited, and is based upon published studies from experimental field trials (see Verulkar et al. 2010). Based on those trials, we determine that the genetic yield potential for BRRI dhan 56 is 5.2 $t\,ha^{-1}$ under optimal conditions; under moderate drought stress, it may yield as high as 3.2 $t\,ha^{-1}$; and under severe drought stress, it may yield up to 1.6 $t\,ha^{-1}$.

Since researchers also claim that BRRI dhan 56 can withstand dry spells for two to three weeks without yield loss, the relative benefits are increasing for dry spells in this range if yields for non-DT varieties decline under these stresses.[5] Due to the absence of studies comparing the performance of BRRI dhan 56 and BR 11, we are not certain if relative benefits begin to decline after roughly three weeks. We do, however, know that yields for BRRI dhan 56 start to decline at this point. Conservatively, in an attempt to take into consideration differences in yield performance on farmer fields versus test plots, we assume that BRRI dhan 56 yields start to decline after a 14-day dry spell, and therefore this becomes our low-threshold trigger, while our high-threshold trigger is an 18-day dry spell. This insurance component closely mimics an insurance product that was marketed as part of a pilot insurance program in Bogra district conducted during *aman* 2013 (prior to the implementation of this present study). This pilot offered insurance products with payouts based on actuarial calculations using data provided by the Bangladesh Bureau of Statistics. The pilot specified indemnities for moderate droughts on a 10 decimal (0.1 acre) plot equal to Tk. 300, while claims on a severe drought paid out Tk. 600 for a 10 decimal plot, corresponding to index triggers of 12- and 14-day dry spells, respectively.[6] Like Lybbert and Carter (2014), we essentially assume that the benefits of bundling the DT component with the insurance component leads to a lateral shift in the insurance component's

[5] These claims are based on translations from the Bangla-language informational brochures prepared by IRRI and distributed under the Cereal Systems Initiative for South Asia (CSISA)-Bangladesh Project.

[6] A dry day was classified as any day during the monsoon season (July 15–October 14) in which less than 2 millimeters of rainfall was recorded.

benefit profile, such that the same indemnities (Tk. 300 and Tk. 600) now correspond to higher triggers (14-day and 18-day dry spells, respectively).

Pricing index insurance requires consideration of the probability that index triggers will be realized and the corresponding indemnity payments that will be made if such triggers are reached, as well as any additional administrative loadings required by the insurer. Because weather shocks that may have the most severe implications for agricultural production are extreme weather events, it is appropriate to model these extrema using an extreme value distribution. The generalized extreme value (GEV) distribution function takes the form

$$F(x;\ \mu, \sigma, \xi) = \exp\left\{-\left[1 + \kappa\left(\frac{x - \xi}{\alpha}\right)\right]^{-1/\kappa}\right\}, \tag{1}$$

where $\xi \in \mathbb{R}$ is the location parameter, $\alpha > 0$ is the scale parameter, and $\kappa \in \mathbb{R}$ is the shape parameter. These parameters can be estimated using maximum likelihood, and the estimates can be used to determine return levels, return periods, and the probability of a extreme event occurring. If the set $\{x_i\}$ is independent and identically distributed from a GEV distribution, then the log-likelihood function for a sample of *n* observations $\{x_1, x_2, \dots, x_n\}$ is

$$\ln\left[L(\xi, \alpha, \kappa|x) = \sum_{i=1}^{n}\left\{-\ln\alpha - \left(1 + \frac{1}{\kappa}\right)\ln\left[1 + \kappa\left(\frac{x_i - \xi}{\alpha}\right)\right] - \left[1 + \kappa\left(\frac{x_i - \xi}{\alpha}\right)\right]^{-1/\kappa}\right\}. \tag{2}$$

With estimates $\hat{\xi}$, $\hat{\alpha}$, and $\hat{\kappa}$, the probability p of event x_p occurring is

$$p = 1 - F(x_p) = 1 - \exp\left\{-\left[1 + \hat{\kappa}\left(\frac{x_p - \hat{\xi}}{\hat{\alpha}}\right)\right]^{-1/\hat{\kappa}}\right\}. \tag{3}$$

A GEV distribution was used to fit 30 years' worth of daily monsoon rainfall data from a weather station in Bogra district and obtain estimates for the location, scale, and shape parameters characterizing the distribution of these maxima. We estimate GEV parameters $(\hat{\xi}, \hat{\alpha}, \hat{\kappa}) = (8.24, 2.09, 0.17)$. With these estimates, we can visualize the shape of the probability distribution function from which these maxima are drawn. The small (and statistically insignificant) shape parameter estimate ($\hat{\kappa} = 0.17, se(\hat{\kappa}) = 0.15$) suggests that a Gumbel (extreme value type I) distribution best fits these data, which further suggests that the underlying rainfall data (or, more appropriately, the lengths of dry spells) from which this sequence of extrema is derived are normally distributed.

Actuarially-fair insurance is priced such that the cost of insurance equals the expected indemnity received. Consider a simple index insurance product with discrete triggers, $i = 1, \dots, n$, and let π_i define the probability of trigger i occurring. Let I_i be the indemnity payout under trigger i. Then an actuarially fair premium would be $A = \sum_{i=1}^{n} \pi_i I_i$. For example, for a full-coverage policy (like the policy offered during the 2013 pilot), indemnities would be Tk. 300 (I_1) for a 12-day dry spell (π_1=0.187) and Tk. 600 (I_2) for a 14-day dry spell (π_2=0.098), for which the actuarially fair cost of insurance would be $A = 0.187 \times \text{Tk. } 300 + 0.098 \times \text{Tk. } 600 = \text{Tk. } 114.90$. For a limited-coverage policy complementing the DT variety, but making the same indemnity payments (that is, Tk. 300 and 600) after 14- and 18-day dry spells, respectively (with $\pi_1 = 0.098$ and $\pi_2 = 0.031$), the actuarially fair cost of insurance would be $A = 0.098 \times \text{Tk. } 300 + 0.031 \times \text{Tk. } 600 = \text{Tk. } 48$.

Clearly, therefore, the limited-coverage policy would be considerably less expensive than the full-coverage policy under actuarially fair conditions. This illustrates how the DT component provides an implicit subsidy on the cost of insurance. In this case, the subsidy is nearly Tk. 67, representing a substantial 58 percent subsidy on the actuarially fair cost of insuring farm income losses from drought. This does not even consider the fact that bundling the DT with WII also reduces the insurer's value-at-risk, which has significant implications for the cost of reinsurance, much of which might also be passed on to the insured in the form of higher administrative loads. Given that many insurance pilots have met such limited success due to insufficient demand, and given many governments' and development practitioners' preferences against providing explicit subsidies, this implicit subsidy may be a powerful tool for providing the incentives necessary to promote widespread adoption of the DT-WII risk management product.[7]

[7] With any index insurance product, there is likely to be some residual basis risk. For the bundled product, this is still the case. But there is evidence to suggest that the degree of basis risk is declining in the severity of the event that comprises the index trigger likely because the spatial correlation in yields increases with hazard severity. Skees et al. (2007, p. 6) note, "if extreme events impact large numbers of households in the same location then basis risk also should be lower for catastrophic loss events."

4. Empirical Approach to Valuation of DT and WII Products

To study farmers' demand for DT and WII products, both independently as well as in a bundled product, we use discrete choice experiments. Choice modeling has become an increasingly important mode of studying economic behavior and demand patterns, as this methodology allows the researcher to estimate marginal values for various attributes embodied in different goods or services, including non-market goods and services for which such marginal valuations are difficult or impossible to measure by examining revealed preferences. Choice experiments represent an alternative to analysis of revealed preference (for example, through *ex post* observation of binding market transactions) or contingent valuation exercises and avoid the weaknesses or pitfalls associated with both. For example, choice experiments allow for *ex ante* analysis of the demand for hypothetical goods or services, or for non-market valuation, which is generally not feasible within a revealed preference framework. Additionally, while well-specified contingent valuation analysis can provide measures consistent with standard welfare economics, they can only compute welfare measures for one-dimensional changes. Because choice experiments elicit valuations for a series of attributes bundled into a good, the results of such experiments can be used to estimate welfare changes for multidimensional changes (Hanley, Mourato, and Wright 2001).

Recently, several studies have used choice experiments to evaluate farmers' preferences for stress-tolerant crop varieties. Birol, Smale, and Yorobe (2012) used a latent class model with two segments to estimate Filipino farmers' preferences for insect-resistant *Bt* maize seed, using seed price, payment method, pest susceptibility, the *Bt* trait (that is, whether the trait is present in the choice task), and seed source information as the relevant attributes.[8] They find significant differences in WTP for the insect-resistance trait between these two classes, suggesting substantial heterogeneity. Ward et al. (2014) studied farmer preferences for DT rice in alternative backgrounds (hybrid versus self-pollinating inbred rice) in Bihar, India. Unlike many other studies of the demand for seeds and traits, this study explicitly acknowledged that farmer seed selection must generally consider not only expected yields but also yields under sub-optimal conditions. To control for this possibility, the researchers include an attribute that reflects a

[8] Insect resistance is conferred from the introduction of genes from *Bacillus thuringiensis* (Bt), a soil-borne bacterium that produces crystalized proteins that are toxic to lepidopteran (chewing) pests such as bollworms.

bundle of yields under different weather conditions (normal conditions, moderate drought stress, and severe drought stress). Their results suggest that there is a great deal of demand for the reductions in yield variability or kurtosis conferred by drought tolerance, with farmers—irrespective of income, wealth, or caste—willing to pay a significant premium above the prices they are currently paying for seed.

In conceptualizing the choice problem, we follow standard conventions and assume that farmers maximize the expected utility of income derived from the production of rice and any insurance payouts they receive. Very generally, our approach proceeds as follows. Suppose that individual i faces K alternatives contained in choice set $\mathcal{S}$ during choice occasion t. We can define an underlying latent variable V_{ijt}^* that denotes the value function associated with individual i choosing option $j \in \mathcal{S}$ during choice occasion t. For a fixed budget constraint, individual i will choose alternative j so long as $V_{ijt}^* > V_{ikt}^* \; \forall k \neq j$. The researcher does not directly observe V_{ijt}^*, but instead observes V_{ijt}, where

$$V_{ijt} = \begin{cases} 1 & \text{if } V_{ijt}^* = \max(V_{i1t}^*, V_{i2t}^*, \dots, V_{iKt}^*) \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

Following standard practice, we assume that indirect utility is linear, which ensures that marginal utility is strictly monotonic in the specified product traits and yields corner solutions in which only one good is purchased (Useche, Barham, and Foltz 2013). We can therefore write individual i's utility function as

$$V_{ijt}^* = X_{ijt}'\beta + \varepsilon_{ijt}, \tag{6}$$

where X_{ijt}' is a vector of attributes for the j^{th} alternative, β is a vector of taste parameters (that is, a vector of weights mapping attribute levels into utility), and ε_{ijt} is a stochastic component of utility that is independently and identically distributed across individuals and alternative choices, and takes a known distribution. This stochastic component of utility captures unobserved (to the researcher) variations in tastes as well as errors in the farmer's perceptions and optimization.

The probability of observing $V_{ijt} = 1$ (that is, the farmer chooses option j given all other alternatives in $\mathcal{S}$) can be written as $\text{Prob}(V_{ijt} = 1) = \text{Prob}\big(X_{ijt}'\beta + \varepsilon_{ijt} > X_{ikt}'\beta + \varepsilon_{ikt}\big) \; \forall k \neq j$.

We assume that the random component of utility ε_{ijt} follows a Gumbel distribution with cumulative distribution function $F(\varepsilon_{ijt}) = \exp[-\exp(-\varepsilon_{ijt})]$ and corresponding probability density function $f(\varepsilon_{ijt}) = \exp[-\varepsilon_{ijt} - \exp(-\varepsilon_{ijt})]$. Rearranging terms, we can easily observe that $\text{Prob}(V_{ijt} = 1) = \text{Prob}\left(\varepsilon_{ikt} < X'_{ijt}\beta + \varepsilon_{ijt} - X'_{ikt}\beta\right) \forall k \neq j$. Then, under the assumption that $\varepsilon_{i1t}, \varepsilon_{i2t}, \dots, \varepsilon_{iKt}$ are independent and identically distributed (iid), we can write our expression for the probability of observing alternative j chosen over all other alternatives conditional upon the observed levels of the attribute vector for all alternatives in the choice set S as

$$\text{Prob}\left(V_{ijt} = 1 | X'_{i1t}, X'_{i2t}, \dots, X'_{iKt}, \beta\right) = \frac{\exp\left[X'_{ijt}\beta\right]}{\sum_{k=1}^{K} \exp[X'_{ikt}\beta],} \tag{7}$$

which is the basic conditional logit model of McFadden (1974) and can be estimated using maximum likelihood. The conditional logit model assumes preference homogeneity, estimating only a single vector β for the entire sample. Within the discrete choice literature, there are several ways of accounting for preference heterogeneity. A common method of evaluating preference heterogeneity is estimation of random parameters logit (RPL) models, also called mixed logit. The RPL is regarded as a highly flexible model that can approximate any random utility model and relaxes the limitations of the traditional multinomial logit by allowing random taste variation within a sample according to a specified distribution (McFadden and Train 2000). Following Train (2003), the probability that individual i chooses alternative j from the choice set S in choice occasion t is given by

$$\text{Prob}\left(V_{ijt} = 1 | X'_{i1t}, X'_{i2t}, \dots, X'_{iKt}, \Omega\right) = \int \frac{\exp\left(X'_{ijt}\beta_i\right)}{\sum_{k=1}^{K} \exp(X'_{ikt}\beta_i)} f(\beta|\Omega) d\beta, \tag{8}$$

where the vector Ω defines the parameters characterizing the distribution of the random parameters, which the researcher can specify. It is somewhat conventional to allow the coefficients corresponding to all attributes except price to vary normally. Price is often restricted to be constant so as to ensure a negative price coefficient, which implies downward sloping demand curves in WTP space.

The use of discrete choice experiments in this study allows us to estimate how much farmers are willing to pay for DT rice, for various types of WII (for example, full versus limited coverage), and for a bundled DT-WII product. Given the utilitarian interpretation of our econometric specification, the K-vector of parameters $\beta = (\beta_{i1}, \beta_{i2}, \dots, \beta_{iK})$ defining tastes and preferences over the K attributes can be interpreted as marginal utilities, and the ratio of two such marginal utilities is simply the marginal rate of substitution of one for the other. If one of the included attributes (say, the K^{th} attribute) is the price of the alternative, then $\beta_{iK} = \beta_K$ can be interpreted as the marginal utility of product price. Assuming this value is negative (therefore representing the marginal disutility associated with increasing prices), and assuming that "a penny saved is a penny earned," the inverse of the marginal disutility of price is simply the marginal utility of money or income. With an estimate for the marginal utility of money, the marginal rate of substitution of money for each of the corresponding attributes—that is, WTP—can be estimated as

$$\mathrm{WTP}_{in} = -\frac{\partial V_i/\partial X_{in}}{\partial V_i/\partial X_K} = -\frac{\beta_{in}}{\beta_K}, n \in [1, N-1], \tag{9}$$

where β_{in} is the estimated parameter for the n^{th} attribute for individual i. The marginal WTP for favorable (unfavorable) attributes will be positive (negative); thus, we must take the negative of this ratio to ensure that the WTP for a favorable (unfavorable) attribute is represented as a positive (negative) value. Obviously, if there are interaction terms included in the utility function, this expression will be slightly different, but such modifications are straightforward: the numerator will simply be the partial derivative of indirect utility with respect to the particular attribute.

For our study, since we are interested in exploring demand for a complementary bundle comprising of DT rice seed and WII, we included two seed-specific attributes, one insurance-specific attribute, and a bundle price attribute in our choice sets. For the seed traits, our approach follows that of Ward et al. (2014) by presenting the yield attribute as yields under different weather conditions. A point of divergence from that study is that the DT rice yields under controlled irrigated conditions (reported as 5.2 t ha^{-1} by Verulkar et al. 2010) are less than the 6.5 t ha^{-1} reported for the widely cultivated BR 11 (Hossain, Bose and Mustafi 2006), so DT rice yields do not exhibit any stochastic dominance over the check variety.[9] Instead, our approach allows for two levels of yields: one roughly corresponding to BR 11 and one roughly corresponding to BRRI dhan 56.[10]

We also consider duration from nursery to harvest, since BRRI dhan 56 is a short-duration strain, allowing for late transplanting in the case of delayed monsoon onset. While this characteristic is not nearly as important (and hence valuable) as yields, Ward et al. (2014) demonstrated that within their sample, farmers did place a premium on medium and shorter durations. This may be a particularly important characteristic of BRRI dhan 56 that may lead to farmers preferring it to BR 11. While BR 11 has higher yields under normal conditions, it is a long-duration variety. BRRI dhan 56 is a short-duration variety, allowing farmers to delay transplanting in the case of delayed monsoon onset or early harvesting, either to avoid late-season droughts, to cultivate a short-duration crop prior to the *Boro* crop, or to begin preparing for the *Boro* crop early. We specified three levels for duration: short (less than 120 days), medium (120–135 days), and long (greater than 135 days).

The insurance attribute consists of varying index triggers and corresponding indemnity payments. Although the insurance product that was offered prior to *aman* 2013 (that is, the full-coverage product) consisted of two triggers with corresponding payments, we decompose these into two separate attribute levels. This allows us to isolate farmers' valuations of each of these trigger/payment combinations. Additionally, we included two levels corresponding to the two triggers and payments from the limited-coverage policy. Assuming additive utility, we can then

[9] No studies have been published demonstrating the performance of BRRI dhan 56 under drought stress conditions in Bangladesh. The field sites in Verulkar et al. (2010) compare the performance of IR 74371-70-1-1 against check varieties in various locations across India, and so do not correlate one-to-one to agroecological conditions in Bangladesh. Given the lack of relevant data, and given the hypothetical nature of the choice experiment exercise, we are comfortable with simply using the reported yield levels under stress conditions reported in Verulkar et al.

[10] To our knowledge, no studies have documented the performance of BR 11 under drought stress conditions. To specify yields under these conditions, we assume that BR 11 performs similar to the average of experimental trials under moderate and severe drought stress. Recall that studies have classified an event as a moderate drought if average yields in the trial decline by 30–65 percent, and a severe drought if average yields in the trial decline by 65–85 percent. We thus assume that BR 11 yields decline by 65 percent under moderate stress conditions and 85 percent under severe stress conditions. In order to convey the message that the relative benefits of DT varieties disappear by the time a drought becomes extreme, we ensure that yields for all varieties converge to some low level such that yields either collapse or are so low as to not warrant harvesting. We assume that yields for BR 11 decline by 95 percent during extreme droughts, so we assume that for all varieties yields under extreme drought stress are 0.325 ton per hectare. Note that since BRRI dhan 56 yields less than BR 11 under normal conditions, the reduction in yields is less than 95 percent, yet the relative benefits are still reduced to zero.

sum the valuations for different combinations of triggers and payments to determine the valuation of a particular insurance product. The insurance attribute will therefore take several levels: no insurance, a policy paying an indemnity of Tk. 300 after a 12-day dry spell ("full coverage, low trigger"), a policy paying an indemnity of Tk. 300 after a 14-day dry spell ("limited coverage, low trigger"), a policy paying Tk. 600 after a 14-day dry spell ("full coverage, high trigger"), and a policy paying an indemnity of Tk. 600 after an 18-day dry spell ("limited coverage, high trigger").

As a final attribute, we included the bundle price to manage risk on 10 decimals of land (0.10 acres). The bundle price takes on a wide range of prices, since the farmer hypothetically could choose to purchase neither DT rice nor WII, could choose one or the other, or could choose both. Including a wide range of prices forces the farmer to make tough choices among the alternatives he or she is presented with, which in turn reveals information about the relative importance of different attributes in his or her utility function. The cheapest option would be for the farmer to purchase neither DT rice nor WII. Farmers can purchase certified seed from Bangladesh Agricultural Development Corporation (BADC) for only Tk. 31 per kilogram, so it is very likely that non-certified seed could be purchased for considerably less than that, especially if the seed were a local variety acquired from an informal source. For non-certified seeds, the risk of non-germination increases, so a greater quantity of seed is generally required to cultivate a given area of land. The seed rate is even higher for farmers directly seeding (as opposed to transplanting), perhaps even as high as 60-75 kg ha^{-1}. For this reason, we have specified our lower-bound price to be Tk. 20 (reflecting the potential cost of purchasing a cheap local variety from an informal source without purchasing insurance). The most expensive option would be to purchase both DT rice and full-coverage WII. Assuming that BRRI dhan 56 will be marketed by BADC for about Tk. 40 per kilogram once seed production reaches a marketable volume, and assuming a modest seed rate of 30 kg ha^{-1} for these newly released improved varieties, combining this with an actuarially fair full-coverage insurance product costing Tk. 115 would yield a realistic price for the bundle at approximately Tk. 150, which we set as the upper-bound price in our choice scenarios. Thus, price levels included in the choice experiment are Tk. 20, Tk. 60, Tk. 80, Tk. 120, and Tk. 150. Of course, for an insurance program to remain viable it should be able to charge administrative and other loadings, so in the absence of subsidies or other assistance, WTP should exceed this actuarially fair price. In the econometric analysis that follows, we treat the price as a continuous variable, which will allow us to estimate the marginal disutility of any incremental increase in cost, which allows us to potentially estimate WTP in excess of these pre-specified bundle prices.

For the choice experiment, we included two hypothetical seed/insurance bundles as well as an option to revert to the status quo (that is, the bundle of seed/insurance that the farmer utilized during the prior *aman* 2013 season). We specified a D-optimal design using a modified Fedorov algorithm with a full-factorial candidate set, eliminating any candidate sets in which one option clearly dominated the other. D-optimality minimizes the weighted determinant of the variance-covariance matrix of the design, where the weight is an exponential weight equal to the inverse of the number of parameters to be estimated. Since we are interested in potential complementarities between these two risk management products, we allow for interactions between the DT attribute and the insurance attribute in our design. This allows us to determine whether the inclusion of WII crowds-in or crowds-out purchases of DT rice, and vice versa. The attributes and corresponding levels considered in our choice experiment are summarized in Table 1.

The discrete choice experiment and supplementary household survey were conducted during May and June 2014 in villages in three *upazilas* (subdistricts) of Bogra district, namely Bogra, Gabtali, and Sariakandi *upazilas* (Figure 1).[11] The sample is largely comprised of households that were interviewed for the 2013 pilot study. In that study, 40 villages were randomly selected from across each of the three *upazilas,* for a total of 120 villages. Households in 60 randomly selected villages were offered WII, while households in the other 60 were not. Within each of the 120 villages, 20 households (on average) were randomly selected from the roster of the local non-governmental organization (NGO) that implemented the insurance pilot in 2013. While our original intent was to interview the same 2,400 households that had participated in the 2013 study, some households had either moved or could not be located. These households were replaced with randomly selected households in the same village that were also participants in the NGO's activities. Our ultimate sample consisted of 2,314 households across the three *upazilas*.

[11] Bogra is the name of one of the *upazilas* in our study area as well as the name of the encompassing district.

5. Results

Estimation results for the choice model using a random parameters logit specification are presented in Table 2. The first set of results is derived from a main effects-only utility specification, while the second set of results incorporates interactions between the DT attribute and the four insurance attributes. The estimates reported in Table 2 are posterior mean marginal utilities and posterior mean standard deviations that are estimated via simulated maximum likelihood. Because utility is a non-cardinal measure, however, these results are not easily interpretable beyond providing information on preference rankings. It is perhaps more informative to examine the monetary valuations of these traits achieved by calculating the average marginal WTP based on equation (9). Table 3 reports estimates of the sample average marginal WTP for a select set of risk management products based on the estimates in Table 2. Specifically, we report the sample average marginal WTP for (1) a short duration DT rice variety (similar to BRRI dhan 56) independent of complementary WII component; (2) a short duration DT rice variety if it were a component of a DT/WII product; (3) a full-coverage WII policy (similar to the one offered as part of the 2013 pilot); (4) a limited coverage WII policy independent of complementary DT; (5) a limited coverage WII product if it were a component of a DT/WII product; and, finally, (6) the bundled DT/WII product introduced in the preceding section.

Based on both sets of regression results, we see that there is generally a negative marginal utility associated with the yield distribution conferred by the DT technology, with a corresponding negative WTP. The negative WTP implies that, by and large, farmers would not adopt the DT variety without significant financial incentives, for example, in the form of a subsidy. On average, we estimate that farmers would require roughly a Tk. 30 subsidy to incentivize adoption of the short duration DT variety on its own. However, since the marginal utility of short duration is greater than the marginal utility of medium duration, which in turn is greater the marginal utility of long duration, it should be duly noted that the necessary subsidy would be substantially greater were this a medium or long duration DT variety. While this may seem relatively surprising, given that the DT variety presents yield advantages over non-DT varieties during moderate and severe drought stress, recall that the variety in question (BRRI dhan 56) does come with a small yield penalty under normal or irrigated conditions. Given that most farmers in our sample have access to irrigation during the dry *boro* season (88 percent of farmers in the sample have access to irrigation on at least one of their plots), it is possible that farmers may simply not care about yields under drought stress because they can simply utilize irrigation to offset any potential damage wrought by extended dry spells. As previously noted, however, it is quite clear that farmers do value short duration. BR 11 is a very long duration variety, so any delay in monsoon onset can delay transplanting and, given its long duration, can have implications not only on the resulting yields but also on the timing of required land preparation in advance of the important and higher-yielding *boro* rice crop that follows the *aman* crop. Short duration not only allows farmers to "escape" droughts arising from delayed monsoon onset but also allows them to harvest earlier, which may insulate their production from damages due to early monsoon cessation. Furthermore, if farmers cultivate short-duration *aman* rice, they may also be able to cultivate a short-duration cash crop (such as potatoes or chilies) in the interim period between the *aman* and *boro* crops. Nevertheless, despite the increased valuation for the short duration DT variety, the marginal WTP is still negative on average, though with a 95% confidence interval spanning zero, we have limited confidence in this sign. Even the upper bound of this confidence interval is less than the expected market price of BRRI dhan 56, however, so it seems unlikely that farmers would willingly adopt BRRI dhan 56 without financial incentives.

Results further suggest that farmers tend to highly value insurance, regardless of whether it offers full coverage or limited coverage. From these results, we estimate that on average, farmers are willing to pay just over Tk. 275 for a limited-coverage policy and just over Tk. 340 for a full-coverage policy. These valuations are well above actuarially fair prices for these instruments (roughly Tk. 48 and Tk. 115, respectively). While farmers are, on average, willing to pay more for the full-coverage policy than the limited-coverage policy, the value that they derive from holding the insurance (relative to the actuarially fair cost of insurance) is much greater for the limited-coverage policy. For the full-coverage, the net benefit perceived is just under double the actuarially fair cost of insurance. For the limited-coverage insurance product, the net benefit perceived is nearly five times as large as the cost of actuarially fair insurance. From a purely economic standpoint, even without being bundled with the DT rice variety, the limited-coverage WII seems obviously preferable to the full-coverage WII. While the high WTP may reflect biased valuations based on receiving insurance indemnities as part of the 2013 pilot, it may also be the case that farmers perceive the triggers to be more likely than the historical data suggest.

Table 4 compares the actual probability of different events occurring, as well as the derived subjective probabilities based on the WTP estimates derived from column (II) of Table 2.[12] These results clearly demonstrate that farmers overestimate the probability of different-length dry spells occurring, and by a large margin. Furthermore, the overestimation is increasing in the length of the dry spell. In other words, farmers overestimate the probability of an 18-day dry spell more than they overestimate the probability of a 14-day dry spell, which they in turn overestimate more than the probability of a 12-day dry spell. Even though historical data suggest that there is only a 3.1 percent probability of an 18-day dry spell, these estimates suggest that farmers, on average, subjectively assess a probability of nearly 30 percent—almost 10 times greater than the data justify. To frame this in terms of return periods, farmers anticipate an 18-day dry spell roughly once every three to four years, when in fact the data suggest that such dry spells should occur, on average, only once every 30 years. In fact, only once in the 30-year series of Bangladesh Meteorological Department data used to construct the index was a dry spell longer than 15 days observed. While this type of behavior may be irrational, it is not unpredictable, and indeed the finding that people tend to overweight the probability of objectively low-probability outcomes when evaluating risky scenarios is a central tenet of prospect theory (Kahneman and Tversky 1979).

The results in column (II) of Table 2, which incorporate interactions between DT rice and the insurance products, and those in Table 3 reveal some interesting insights regarding the perceived complementarities between these two risk management tools. In Table 3, we present WTP estimates for short duration DT rice and the insurance components under different scenarios, which can be conceptualized in terms of whether the component is "bundled" or "unbundled." These differ in how the binary interacting effects are treated in the partial derivatives when computing marginal utility and the marginal rates of substitution of money for incremental additions of the different bundle components. Rather than simply evaluating the interactions at the means, we evaluate the interactions at different levels (0 or 1) and compute the marginal WTP under these alternative scenarios. For example, row (1) of Table 3 reports the marginal WTP for the DT rice component in the unbundled case and assumes that there is no insurance, so

[12] These subjective probabilities are derived assuming that farmers' WTP for a particular insurance product is equivalent to their expected payout. Essentially, therefore, these subjective probabilities assume that farmers' WTP is their assessment of an actuarially fair price for the insurance product in question. We then simply calculate the perceived probability, averaged across all farmers, for the trigger event that satisfies this assumption.

despite the positive regression coefficient associated with the interaction term in column (II) of Table 2, the absence of an insurance component implies that the *interaction effects* drop out of the marginal utility of DT and WTP is essentially calculated based only on the main effect. Note that the estimates reported in rows (2) and (5) of Table 3 are marginal WTP for the *components* of a hypothetical bundle—not for the entire bundle. The marginal WTP for the full DT/WII bundle is reported in row (6) of Table 3.

From these results, we first note that the WTP for unbundled DT rice (which is computed based simply on the main effect in column II of Table 2, assuming no WII) is negative, again indicating that farmers, on average, would not willingly adopt a DT variety based solely on the reduced yield variability under moderate and severe drought conditions, or at least not without financial incentives. But we see from column (II) of Table 2, there are positive coefficients on the interaction terms (though not all are statistically different from zero), which suggests that the marginal utility of DT rice increases if the seed is bundled with insurance. This is evident from the increasing (though, on average, still negative) WTP for the DT-seed component of a DT/WII bundle reported in row (2) of Table 3. The positive interaction coefficients also imply that farmers' valuations of the insurance products increase when they are bundled with DT rice. On average, farmers would be willing to pay roughly Tk. 280 for an unbundled limited-coverage insurance product; if it were bundled with DT rice, however, farmers would be willing to pay more than Tk. 340 for the insurance component. If we consider that these valuations reflect farmers' perceptions about the benefits of the different products, we note that farmers value the bundled limited coverage WII product as much as the independent full-coverage WII product, even though the full-coverage WII policy pays out indemnities on much more likely events and therefore yields an objectively higher expected value.

Clearly, therefore, if farmers are willing to pay more for these two components if they are bundled together, the valuation of the bundle is greater than the sum of the valuations of the components taken individually. For example, farmers on average would be willing to pay an approximately Tk. 375 for a bundle including a short-duration DT rice (similar to BRRI dhan 56) and a limited-coverage WII policy. If the insurance were not bundled with the short duration DT variety, however, they would be willing to pay only about Tk. 280 for the limited-coverage WII policy, and would not be willing to pay anything for the DT. This is an important result, as it very strongly suggests that farmers perceive these tools to be complementary, providing greater value when they are bundled together into a comprehensive, complementary risk management product. Furthermore, while unbundled BRRI dhan 56 does not appear to be a viable technology in our sample area (given the negative or at best zero marginal WTP), bundling BRRI dhan 56 with an insurance product would greatly increase adoption and, presumably, cultivation. In a sense, the insurance crowds-in adoption of BRRI dhan 56, though, because of the manner in which our choice sets are constructed, this result may arise only if the two products are bundled and not if farmers have to shop around for risk management tools to build their own such DT-WII bundle.

6. Conclusions and Policy Implications

In this study we have used discrete choice experiments to study farmers' demand for DT rice varieties and WII based on the length of maximum *aman* (monsoon) season dry spells in several *upazilas* in northwestern Bangladesh. We have shown that, conceptually, these two tools for managing drought risk can be bundled together to provide a product that comprehensively addresses nearly the full spectrum of drought risk, subject to the obvious limitations associated with basis risk, the accuracy of the underlying index data, and related constraints. The calibration of such a bundle—specifically, the design of the insurance product—requires careful consideration of the performance characteristics of the DT variety that it is being bundled with. With this in mind, we have demonstrated how such a product could be designed assuming that the relative benefits of the DT rice begin to decline when droughts go from being merely moderate to more severe.

The results of our discrete choice experiment suggest that farmers in our sample view these two instruments in a manner consistent with our conceptual framework. On average, farmers would not be willing to pay for the reductions in yield variability conferred by a DT variety like BRRI dhan 56, as there is a yield penalty under normal or irrigated conditions. Because most farmers in our sample have access to irrigation during *boro* (winter season) rice cultivation, such sources can also be utilized to hydrate crops during prolonged dry spells that might occur during *aman* rice cultivation. It might therefore be the case that farmers in our sample do not really face the production risks that a DT variety like BRRI dhan 56 would address. Furthermore, since the relative benefits of DT rice are most observable during moderate droughts (when the relative benefits vis-à-vis non-DT varieties are both positive and increasing), farmers with access to supplemental irrigation might never likely observe these relative benefits and would furthermore be quick to disadopt in favor of a higher-yielding variety like BR 11. However, results suggest that the short duration of BRRI dhan 56 is appealing, as it not only allows farmers to escape droughts occurring at either end of the monsoon season but also provides a window in which farmers can cultivate a short-duration crop between *aman* and *boro* seasons that can be marketed to provide additional liquidity to help offset some of the hardships often endured in the lean season immediately following *boro* transplanting.

In contrast, farmers value the insurance products offered significantly more than their actuarially fair values. This is an interesting and somewhat surprising result, as the conventional wisdom—as well as several empirical studies—suggests that farmers around the world do not have an appropriate appreciation for the value of agricultural insurance and would not typically be willing to pay an actuarially fair price, let alone a price that includes any risk or administrative loads required by the insurer. Furthermore, in the case of our sample, because almost all the farmers in our sample have access to supplemental irrigation on a fixed cost basis, it is not apparent that droughts pose a significant risk to *aman* rice production.

Unlike DT rice, however, the insurance products are not tied to a particular crop, so our estimates suggest that farmers may view the potential payouts offered by the insurance products as a valuable tool for offsetting drought losses perhaps not directly related to their rice crops, such as losses to fish or livestock, or to other monsoon-season crops grown on plots without access to irrigation, such as horticultural or vegetable crops. These higher valuations also suggest that farmers in our sample overestimate the probabilities of prolonged dry spells occurring, therein overestimating the probability that the insurance will pay out indemnities. Given that farmers in developing countries are often found to be risk averse, the mere presence of background risk can lead to sub-optimal investments in inputs that may increase agricultural productivity and enhance rural livelihoods. Providing farmers with access to such insurance instruments that they clearly value greatly may provide the peace of mind needed for farmers to be willing to take higher production risks that offer potentially higher returns.

When we consider bundled DT/WII products, our results suggest that farmers, on average, view these as complementary tools for addressing drought risk, such that the valuation for one component is increasing if the other component is present. Consequently, if farmers were presented a menu comprised of DT rice, a full-coverage WII product, and DT rice bundled with a limited-coverage WII, our results suggest that they would most likely prefer the bundled product, though uncertainty in the valuations makes it difficult to differentiate farmers WTP for the full-coverage insurance product and this bundle. Nevertheless, this could provide an opportunity to "nudge" farmers into opting for the complementary bundle: if farmers were presented with these three options, we might expect, on average, that most farmers would purchase the bundled product containing the short duration DT rice variety and the complementary limited-coverage WII product. While it can be argued that limiting the choice space over a series of second-best alternatives would result in lower household welfare, we have attempted to demonstrate that there are degrees of second-best options available, with some being clearly better than and preferable to others, and that restricting access to poorer second-best may result in net welfare gains.

It remains to be seen whether the bundled risk management package results in appreciably different short- and long-run behavior vis-à-vis either insurance or other more traditional forms of risk management. This, we feel, is a fruitful area of inquiry that we expect to see researchers explore in the coming years. On the whole, our results suggest that bundling DT rice with WII may have additional benefits beyond merely providing a mechanism for managing risk. We have previously observed that many farmers in our sample area have access to irrigation during the dry *boro* season, and may eventually start accessing these groundwater resources to provide supplemental irrigation during rainfall deficiencies in the *aman* season. Being able to access irrigation so easily without additional variable costs may result in over extraction of groundwater, as there are no financial incentives for farmers to conserve water. Often, the decision to access supplemental irrigation is based on visual cues, such as browning of the rice leaves or drying and cracking of the soil. Since BRRI dhan 56 can withstand rather long periods (perhaps as long as 21 days) without water, even during reproductive stages, it is possible that it will stay greener longer, which may lead farmers to wait longer before irrigating or to use less water overall. Given the novelty of this technology, there is no substantive evidence to this effect, but the causal chain is at least plausible. This remains a potentially fruitful area for future research and may have long-term implications for water markets and water pricing in rural Bangladesh.

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Table 1. Summary of attributes and levels included in discrete choice experiment

Attribute	Level	Variety	Normal conditions	Moderate drought stress	Severe drought stress	Extreme drought stress
Potential yields under various weather conditions (t ha^{-1})	**1**	Non-DT	6.5	2.6	1.0	0.3
	2	DT1 (BRRI dhan 56)	5.2	3.2	1.6	0.3
Duration (days from nursery to harvest)	***Level***	***Label***	***Days***			
	1	Short	< 120			
	2	Medium	120–135			
	3	Long	> 135			
Weather index insurance	***Level***				***Trigger (consecutive dry days)***	***Indemnity payment (Tk.)***
	1	No insurance				
	2	Full coverage, low trigger			12	300
	3	Full coverage, high trigger			14	600
	4	Limited coverage, low trigger			14	300
	5	Limited coverage, high trigger			18	600
Bundle price	***Level***	***Bundle price (Tk.)***				
	1	20				
	2	60				
	3	80				
	4	120				
	5	150				

Source: Authors.

Table 2. Random parameters logit results

	(I)			(II)		
	Coefficient		Standard error	Coefficient		Standard error
Random parameters						
Drought tolerant (DT) rice	-1.314	***	0.056	-1.654	***	0.146
Short duration (SD)	1.428	***	0.066	1.424	***	0.066
Medium duration	0.530	***	0.050	0.520	***	0.053
Limited coverage, low trigger	1.043	***	0.078	0.976	***	0.100
Limited coverage, high trigger	1.339	***	0.104	1.324	***	0.151
Full coverage, low trigger	1.108	***	0.089	0.860	***	0.114
Full coverage, high trigger	1.937	***	0.083	1.959	***	0.103
Nonrandom parameters						
Price (Tk. 100)	-0.779	***	0.058	-0.834	***	0.063
DT rice × Limited coverage, low trigger				0.287	*	0.155
DT rice × Limited coverage, high trigger				0.239		0.196
DT rice × Full coverage, low trigger				0.624	***	0.174
DT rice × Full coverage, high trigger				0.233		0.151
Alternative-specific constant - status quo	-5.712	***	0.249	-5.605	***	0.257
Distributions of random parameters						
SD (DT rice)	1.304	***	0.070	1.320	***	0.071
SD (Short duration)	0.858	***	0.089	0.885	***	0.091
SD (Medium duration)	0.033		0.053	0.035		0.059
SD (Limited coverage, low trigger)	0.015		0.034	0.017		0.034
SD (Limited coverage, high trigger)	0.726	***	0.200	0.761	***	0.208
SD (Full coverage, low trigger)	0.300	*	0.165	0.283	*	0.163
SD (Full coverage, high trigger)	0.440	***	0.132	0.524	***	0.126
Number of households (n)	2,314			2,314		
Number of choice sets per household (T)	5			5		
Total number of observations (N=nT)	11,570			11,570		
Number of parameters (K)	16			20		
Log likelihood	-6,546.53			-6,535.93		
Adjusted pseudo-R^2	0.48			0.49		
AIC (Akaike Information Criteria)	13,137.06			13,115.87		
BIC (Bayesian Information Criteria)	-6,443.61			-6,433.02		

Source: Authors.

Note: *** significant at 1% probability of type I error; ** significant at 5% probability of type I error; * significant at 10% probability of type I error. Random parameters logit model estimated using NLOGIT 5.0 based on 1,000 Halton draws used for simulated maximum likelihood. Models assume non-price main effect marginal utility coefficients are normally distributed.

Table 3. Empirical estimates of willingness to pay (WTP) for risk management products

	Risk management product	Mean WTP	95% CI
(1)	WTP for short duration drought-tolerant (DT) rice seed[a]	-27.36	[-63.54, 9.91]
(2)	WTP for short duration DT rice seed[b]	34.84	[-17.32, 83.87]
(3)	WTP for full coverage weather index insurance (WII) policy[a]	340.63	[276.09, 414.71]
(4)	WTP for limited coverage WII policy[a]	278.42	[206.22, 364.73]
(5)	WTP for limited coverage WII policy[c]	340.81	[267.84, 429.17]
(6)	WTP for short duration DT + limited coverage WII policy	375.47	[284.25, 472.08]

Source: Authors.

Note: [a] Unbundled, main-effect only; [b] Bundled with limited-coverage weather index insurance product; [c] Bundled with drought-tolerant rice. Means and 95% confidence intervals derived based on the parametric bootstrap procedure introduced by Krinsky and Robb (1986) based on 1,000 random draws from a multivariate normal distribution with means and variance-covariance matrix of the estimated (posterior) model parameters. For products (2) and (5), the sample mean WTP estimates reported are for the listed component only and do not factor in WTP for the other component(s) of the specified bundle.

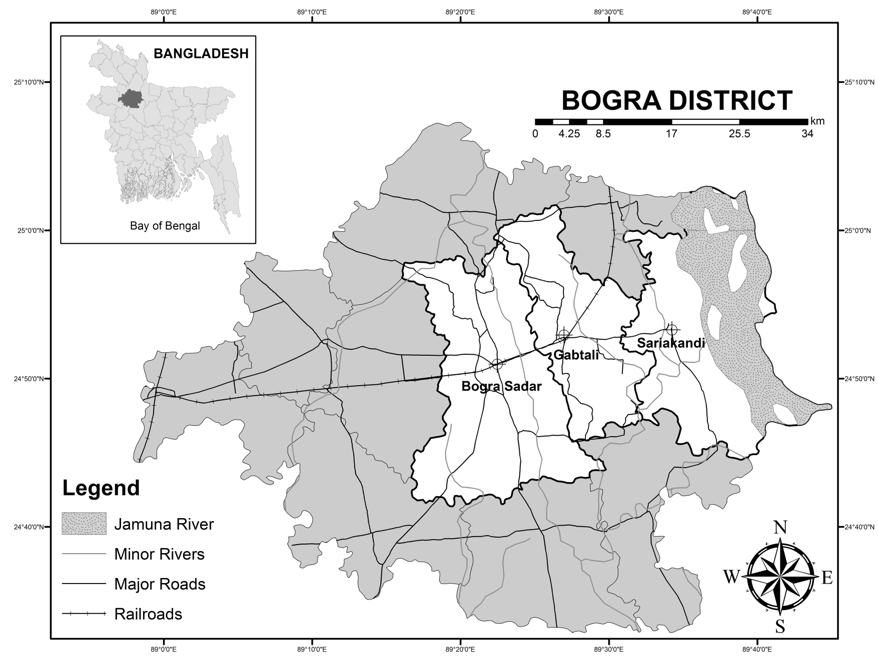
Table 4. Farmers' subjective assessments of probabilities of different-length dry spells

Length of dry spell	Actual probability	Subjective probability
12 days	0.187	0.478
14 days	0.098	0.417†
14 days	0.098	0.451††
18 days	0.031	0.289

† Based on mean willingness to pay (WTP) for full-coverage, high-trigger insurance
†† Based on mean WTP for limited-coverage, low-trigger insurance

Source: Authors.

Figure 1. Bogra district, Rajshahi division, Bangladesh



Source: Authors.