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Demand for Complementary Financial and Technological Tools for Managing Drought Risk

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Contents

Tables

Figures

ABSTRACT

Weather-related production risks remain one of the most serious constraints to agricultural production in much of the developing world. Financial and technological innovations that mitigate these risks have the potential to greatly benefit farmers in areas prone to such risks. 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 potential for these tools to be combined in a complementary risk management product. Using a discrete choice experiment, we assess farmers' preferences for these two tools independently and in a bundled package. Findings indicate that farmers are generally unwilling to pay for drought-tolerant rice independent of insurance, largely due to the yield penalty under normal conditions. When bundled with insurance, however, farmers' valuation of the rice increases. Farmers value insurance on its own, but even more so when bundled with the drought-tolerant rice 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

Farming systems in Bangladesh have traditionally been at the mercy of the weather, and weather hazards such as droughts and floods have historically had large impacts on agricultural production. Given the anticipated pace of climate change, the frequency of weather-induced shocks is not likely to diminish in the near future (IPCC 2007). Evidence suggests that among developing countries, Bangladesh will be one of the hardest hit by climate change (Nelson 2009), making farmers particularly vulnerable to abiotic stresses such as droughts and floods that disrupt agricultural production.

Droughts have been identified as a particularly serious constraint to rice production in South Asia (Huke and Huke 1997; Pandey, Bhandari, and Hardy 2007; Serraj et al. 2009; Kumar and Quisumbing 2011). 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.[1] These constraints are 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 on production. In the absence of formal means to manage these covariate risks, households often rely on informal risk-coping mechanisms such as savings, credit, gifts, and loans (Clarke et al. 2012a). The effectiveness of such measures has been questioned by Santos et al. (2011), highlighting the need for more formal mechanisms to reduce ex ante risks to households. Even when droughts do not occur, drought risks reduce rice productivity because farmers avoid investing in high-risk high-return inputs when they fear crop loss (Pandey, Bhandari, and Hardy 2007) and continue to make low-risk low-return investments, remaining trapped in a vicious circle of poverty (Barnett, Barrett, and Skees 2008). Hence, there is a need to continuously devise innovative and inexpensive strategies to manage risks that pose significant threats to farmers' livelihoods.

Bangladesh has 5.46 million hectares of drought-prone areas, mainly located in the country's northwestern and northern regions. Droughts in these regions are most commonly associated with the delayed arrival or early cessation of annual monsoon rains, although intermittent dry spells during critical stages of *aman* (monsoon season) rice production can also have serious implications. Delayed monsoon onset (June–July) can postpone transplantation, which, in turn, shortens the growing season while also potentially affecting the timing of activities for the subsequent crop. The early cessation of monsoon rains (September–October) during the heading, budding, flowering, and grain-filling stages of plant growth can reduce yields and also delay sowing for subsequent crops. 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).

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, weather index insurance (WII), 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 fashions. As such, farmers potentially view these as either substitutable or complementary risk management tools, depending on various factors such as the farmers' exposure to risks, whether the risks are related to crop failure or to the additional costs of supplemental irrigation during dry spells, the performance parameters of the DT rice variety, and the structure of the insurance contract. We demonstrate the potential to combine these two tools into a complementary package that provides comprehensive drought risk management, and, through a discrete choice experiment carried out in a drought-prone district in northwestern Bangladesh, we explore farmers' willingness-to-pay for each of these tools independently as well as in a complementary bundle.

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[1] In South Asia, a large proportion of rice is cultivated during the monsoon season. When monsoon rains are late in arriving, farmers will often delay transplantation and in some cases reduce the area under paddy cultivation. Lower yields arise due to either a shorter growing season (for example, due to delayed monsoon onset or early monsoon cessation) or inadequate cumulative rainfall, which inhibits plant growth.

2. TECHNOLOGICAL AND FINANCIAL TOOLS FOR MANAGING DROUGHT RISKS

Drought-Tolerant Rice

Bangladesh has extensive experience with technologies designed to manage weather risk. The introduction and rapid expansion of shallow tube wells for irrigation has led to dramatic expansion of *boro* rice production during the dry winter season, and the introduction of new rice varieties for *boro* production have contributed significantly to boosting yields and output (Hossain et al. 2012). The impact pathways through which technology contributes to household welfare improvement are fairly well understood. Technological changes are designed to increase yield or reduce production costs, leading to either (1) increases in the availability of food staples for household consumption or (2) increases in marketable surpluses of food staples that increase household income. In turn, these changes provide households with the additional financial, human, and capital resources needed to smooth consumption, invest in productive assets, and reduce vulnerability to shocks. However, most of these technologies allow households to manage risks only through diversification or ex post consumption smoothing, while few provide effective strategies by which households can adequately insure themselves against major or catastrophic risks such as prolonged drought or flood that can entirely devastate production.

The development of abiotic stress–tolerant traits in a variety of crops has been seen as a potential avenue through which human livelihoods can be at least partially insulated from the effects of weather-related risks. Some abiotic stresses that have received attention from researchers and plant breeders include drought, anaerobic germination, salinity, submergence, ferrous toxicity, and both low and high temperatures. While researchers have acknowledged the threats posed by droughts, only recently has drought tolerance received a significant degree of attention from plant breeders (Doering 2005).

In 2011, the Bangladesh Rice Research Institute (BRRI), with technical support from the International Rice Research Institute (IRRI), released BRRI dhan 56 (with genomic line number IR 74371-70-1-1), a drought-tolerant (DT) paddy variety suitable for cultivation in rainfed areas in Bangladesh during the *aman* season. BRRI dhan 56 is a short-duration variety, maturing in roughly 105–110 days.[2] This short duration provides a means of escaping either early or late season droughts, but in and of itself the variety's short duration provides little protection against droughts that occur during crucial periods of development, such as flowering. In addition to providing a means of escaping droughts, the short duration also offers farmers opportunities to harvest their *aman* rice crop at full maturity and begin early preparation for the winter crop.[3] 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* cultivars. 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.[4] But while BRRI dhan 56 may provide yield benefits relative to other varieties under moderate and even severe droughts, the resultant yields under these drought stress conditions are still roughly 40 and 70 percent lower than under well-irrigated conditions, respectively. It is not likely, therefore, that farmers would simply rest on the dehydration tolerance that is embodied in

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[2] For purposes of comparison, BR 11, the most widely cultivated transplanted *aman* (*T. aman*) variety, has a duration of 145 days.

[3] 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 winter crop.

[4] 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.

BRRI dhan 56 under prolonged dry spells, as the resultant yields may be insufficient to provide necessary levels for subsistence, let alone any marketable surplus.

While not specifically concerning themselves with rice, Lybbert and Bell (2010) have noted 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, and may be viewed as a lost payment in years in which there is no drought and in which the benefits of the DT variety vis-à-vis the non-DT variety are not realized. Unlike insurance, however, Lybbert and Bell note that the "terms" of the insurance are concealed from the farmer, muting any spillover benefits. In addition, the conjoint nature of drought risk and DT characteristics makes adoption pathways significantly more complicated than the pathways for innovations such as genetically modified insect-resistant crops.[5]

Among other important differences, Lybbert and Bell (2010) argue that drought tolerance introduces non-monotonic benefits relative to non-tolerant varieties, which, as a productivity-*enhancing* (yield-variability reducing) benefit rather than purely a productivity-*increasing* (yield increasing) benefit, introduces stochastic-relative benefit streams that may complicate the decision-making calculus of risk-averse farmers.[6] Consider Figure 2.1 (adapted from Lybbert and Carter 2014), which illustrates the non-monotonic benefits of DT varieties relative to non-DT varieties at varying degrees of drought stress. Assume that drought stress D (measured as maximum number of consecutive dry days) takes a generalized extreme value distribution, with probability density function $g(D)$ as illustrated. Under normal conditions, we can assume that there is no relative benefit: the DT variety performs neither better nor worse than the non-DT varieties. Under moderate drought stress, the performance of non-DT varieties begins to suffer, while the DT variety maintains its yields (or at least yields do not decline as fast as those of non-DT varieties). In this region, there are positive and increasing relative benefits, $y(D)$. Once the drought becomes severe, however, the relative benefits of drought tolerance begin to decline. Yields are still higher than those of non-DT varieties, but the yield advantage is diminishing. Once the drought becomes extreme, the relative benefits of drought tolerance are exhausted, and the yields of the DT variety are virtually indistinguishable from those of non-DT varieties. In this region, it can be assumed that both DT and non-DT crops would fail, or would yield so little as to not even justify harvesting. As it is presented, the relative benefits of drought tolerance take a triangular distribution under moderate to severe droughts. This is, of course, a simplification, but helps to illustrate the non-monotonic nature of benefits of DT relative to non-DT varieties.

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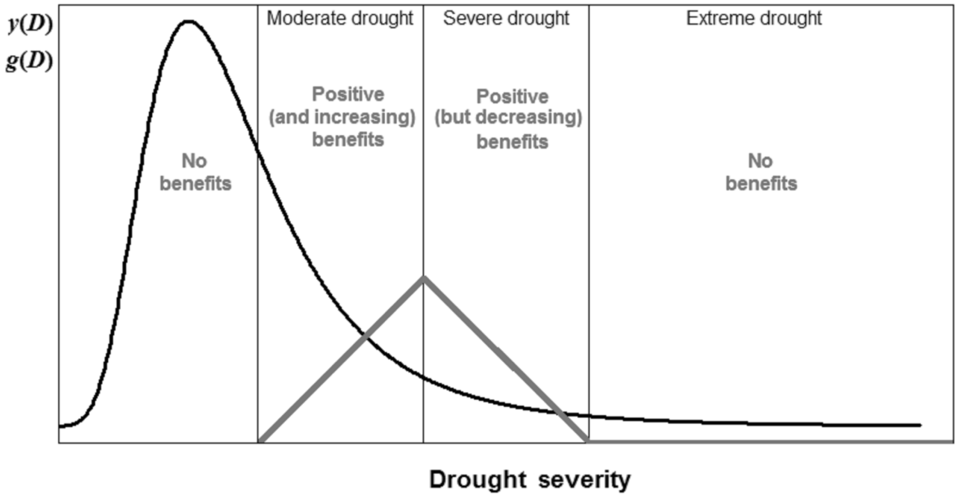
[5] The genetically modified insect-resistant crops referred to here share a similar insect-resistance trait that is conferred by the introduction of genes from the soil bacterium *Bacillus thuringiensis* (Bt) into their DNA. While Bt cotton and Bt maize are the largest commercial applications of this technology, Bt has also been introduced into potato, soybeans, and brinjal (eggplant), among other crops.

[6] We define a productivity-*enhancing* benefit as one that either increases yield or reduces yield variability or yield susceptibility to stress, while a productivity-*increasing* benefit more narrowly only increases yield. In this regard, productivity-enhancing technologies involve higher-order moments of the yield distribution, while productivity-increasing technologies involve only the first-order moment.

Figure 2.1 Relative benefits of drought-tolerant (DT) crops under different degrees of drought stress



Source: Authors' creation based on Lybbert and Carter (2014).

Weather Index Insurance

Financial mechanisms for dealing with risks include traditional crop insurance, micro-savings, micro-credit, crop loans, catastrophic insurance, disaster payments, and index insurance. Many of these financial services work in a similar manner: by lowering the household's liquidity constraint, they allow fungible resources to be reallocated to consumption and investment activities that improve on-farm productivity, increase consumption, and reduce vulnerability. Micro-credit and micro-savings have been widely used in Bangladesh, although standard 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). WII is viewed by many as an increasingly popular alternative to standard crop insurance, particularly for rural households in developing countries that do not generally have access to other financial instruments to help them cope with weather-related shocks that threaten livelihoods (Skees 2008). WII is a specific type of index insurance product that offers indemnity payments based on the realization of specific weather variables measured over a pre-specified period of time at particular weather stations (World Bank 2011). The index trigger is typically calculated using historical data, and indemnity payments are made to the insured when the realized value of the weather variable crosses a pre-specified threshold, usually a specific deviation from long-run average measures. Variables such as rainfall or temperature or various combinations are generally used. Such index variables are exogenous to the individual policyholder but have strong correlation with farm-level yields or losses.

Index-based insurance products have several advantages over traditional crop insurance. First, indemnity payments are based on index triggers that are easily observable and measurable. For example, many of the variables over which these indexes are constructed are related to weather, for which data are often collected at spatially disaggregated scales by national or subnational meteorological departments at weather stations (World Bank 2011). Using such widely observable measures increases the indexes' transparency, minimizing asymmetric information and reducing the probability of adverse selection and moral hazard (Clarke et al. 2012a; Clarke, et al. 2012b; Ruck 1999; Ibarra and Skees 2007). Second, the ease with which the index triggers are observed and measured allows for indemnity payments to be calculated easily and potentially distributed in a timely manner (Turvey 2002). This can be very important for farmers who need injections of liquidity to adapt to the weather stress, and can save farmers from distress sales of productive assets (for example, livestock), which can have long-term livelihood implications. Third, because indemnity payments are based on an index rather than loss adjustments calculated for each farm that is insured, operating costs are significantly lower than those of other types of agricultural insurance. In many instances, the indexes can be based on variables for which data are publicly available, significantly reducing the costs associated with monitoring losses. Contracts are standardized and need not be tailored to the individual needs of different policyholders (Skees 2008). Additionally, 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, evidence suggests that reinsurers are likely to reduce uncertainty loading on WII products (World Bank 2011). This, in turn, lowers the administrative costs for the index insurance providers, which may result in lower total insurance costs for the farmers acquiring the insurance.

Despite these benefits, there are also significant challenges to WII. First, setting up the index parameters can be technically complex, as will be discussed in greater detail below. Part of the complexity lies in the specification of appropriate weather parameters with which to construct the product's index. In order to add the most value to policyholders, the weather variables should be highly correlated with actual agricultural losses. Some examples include rainfall deficits, rainfall excesses, high temperatures, evapotranspiration rates, low temperatures, high wind speeds, wind directions, sunshine hours, and consecutive dry days (World Bank 2011). The degree to which these variables are correlated with agricultural losses is likely to be very context-specific, depending on, among other things, broader agro-ecological conditions. To properly construct a weather index, one must have reliable and spatially disaggregated data on the weather variables being used—variables that are not always available in developing countries. In addition, where data come from weather stations, there is a need for the weather stations to be sufficiently secure from tampering to ensure the integrity of the weather data and the associated index.

A second—and more significant—challenge to WII is basis risk. Basis risk refers to the potential mismatch between the index trigger and actual on-farm losses. 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 weather conditions experienced by farmers will differ from weather conditions recorded at the weather station. It is possible, therefore, that farmers could receive indemnity payouts when they have not actually experienced a loss because a weather shock is reported at the reference weather station or, more troubling, that they may *not* receive a payout when they have actually experienced a significant loss if the weather shock is not reported at the station. Various studies have empirically examined the sensitivity of farmers to basis risk and the effectiveness of index insurance in the presence of basis risk (Barnett et al. 2005; Black, Barnett, and Hu 1999; Deng et al. 2007; Martin, Barnett, and Coble 2001; Turvey 2001; Vedenov and Barnett 2004; Wang et al. 1998).

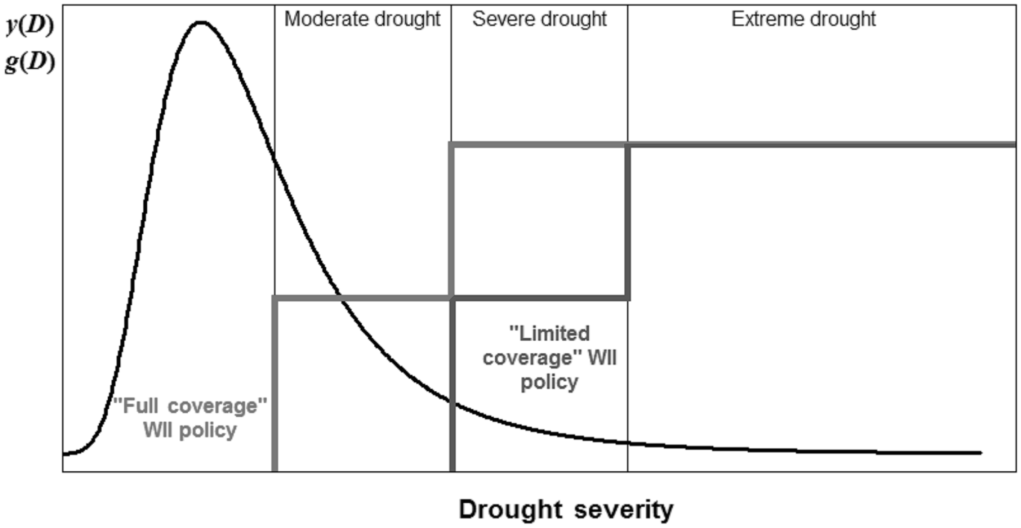
There are several ways to reduce basis risk. One way is to base the insurance on highly covariate weather risks that affect most people in a particular geographic area. Basis risk can also be reduced by increasing the number and distribution of weather stations, as this presumably reduces the distance between the farm and the weather station, which in turn reduces the probability that on-farm weather conditions differ from those of the weather station on which the indemnity payments are based. It may also be the case that basis risk is declining in the severity of the weather stress if, for example, the spatial correlation in yield losses is positively correlated with the weather stress. Skees, Hartell, and Muphy (2007, 6) note that "if extreme events impact large numbers of households in the same location then basis risk also should be lower for catastrophic loss events." There is some anecdotal evidence that this is indeed the case. Rowley, Price, and Kastens (2007), for example, demonstrate that the degree of harmony in farmers' perceptions of drought severity (based on actual losses) was positively correlated with Normalized Difference Vegetation Index (NDVI) scores indicating actual drought severity, suggesting a greater correlation in farmers' actual losses with increasing drought severity. Structuring WII to manage risks of extreme droughts (rather than more moderate droughts) would, therefore, presumably manage risks that have a higher degree of spatially correlated damages, thus resulting in lower basis risk.

Surprisingly, there have been relatively few studies that attempt to elicit farmers' valuations of agricultural insurance, and even fewer involving index-based insurance. Rare examples include Patrick (1988); McCarthy (2003); Sarris, Karfakis, and Christiaensen (2006); Hill, Hoddinott, and Kumar (2013); and Cole, Giné, and Vickery (2013). The few existing studies examining willingness to pay (WTP) for index insurance seem to suggest that in the absence of some intervention subsidizing the premiums, most farmers are not willing to pay even the actuarially fair cost for such insurance, let alone risk-adjusted premiums or premiums with any sort of administrative or operating loads. Patrick (1988) found that less than half of a sample of wheat producers in Australia would participate in a rainfall insurance program, and less than 12 percent would be willing to pay more than the expected value of the rainfall insurance indemnities based on long-run rainfall probabilities. McCarthy (2003) found that farmers in Morocco were generally interested in rainfall index insurance, and in some cases were willing to pay over and above the expected indemnities. But even in cases in which farmers were willing to pay above expected indemnities, the excess valuations were so low that any administrative or overhead loads might crowd out demand. Sarris, Karfakis, and Christiaensen (2006) found that less than half of households in their sample of Tanzanian farmers were interested in index insurance, with fairly wide heterogeneity. Estimating farmers' WTP for various insurance contracts, they found that farmers were, on average, willing to pay far less than the actuarially fair price for insurance, and many farmers actually assigned negative valuations to the insurance. The valuations were increasing with the contract's stated indemnity and with the probability of the indemnity being triggered, but valuations were still, on average, less than 25 percent of the expected indemnity. One recent study provides evidence that farmers do effectively value WII products. Cole, Giné and Vickery (2013) used a Becker-DeGroot-Marschak (Becker, DeGroot, and Marschak 1964) mechanism to elicit farmers' WTP for index insurance policies. Unlike other methods of eliciting WTP, farmers faced with these mechanisms actually purchase insurance policies if their stated bids exceed a randomly selected offer price. On average, Cole, Giné and Vickery found that farmers' valuation of the index insurance policy exceeded the estimated actuarially fair price. In fact, the average WTP was 26–55 percent higher than the estimated actuarially fair price, suggesting viability for index insurance, at least among their sample in Andhra Pradesh, India.

A handful of evidence-based studies have examined the determinants of index insurance uptake to better understand the barriers to adoption of such risk management tools. Consistent with standard theory on insurance demand, Cole et al. (2013) found among a sample of Indian farmers that uptake was fairly income-elastic, with higher uptake among wealthy households and lower uptake among poor and credit-constrained households. A study in Ethiopia by Hill, Hoddinott, and Kumar (2013) also suggests that wealthy, rich, and proactive farmers will likely be the dominant entrants into insurance markets. These results comply with the theoretical model of rational demand for indexed products provided by Clarke (2011). Other factors found to be positively related to insurance take-up are social networking and the household's degree of familiarity with the insurance product and vendor (Cai 2013; Giné, Townsend, and Vickery 2008; Giné, Karlan, and Ngatia 2011; Cole et al. 2013). In addition to evaluating WTP for index insurance, Cole et al. (2013) studied the effects of insurance on farm production behavior based on a randomized controlled trial in Andhra Pradesh, India. They found that the provision of insurance caused significant shifts in the *composition* of agriculture investment, though with little change in the total *level* of investment. Insured farmers invested in cash crops, which provide higher expected returns but are more sensitive to rainfall. These farmers also allocated more agricultural inputs (fertilizer, seeds, land) to the production of these cash crops. The effects were not universal, however. Insurance provision had the greatest effect on production decisions among educated farmers, as measured by years of schooling. Among literate farmers, the purchase of insurance increased the probability of investing in cash crops, while there was no significant effect among illiterate farmers.

Figure 2.2, drawing again from Lybbert and Carter (2014), illustrates how a WII product could work to address drought risk. In this figure, two types of policies are illustrated, one of which can be conceptualized as a "full coverage" policy for which benefits (actually indemnity payments)—denoted $y_1(D)$—are triggered by the occurrence of moderate (T_0) and severe (T_1) droughts, and one that can be thought of as a "limited coverage" or "catastrophic" policy for which benefits—denoted $y_2(D)$—are triggered only during severe (T_1) or extreme (T_2) droughts. In this figure, each policy has two triggers, a "low trigger" and a "high trigger." At the low trigger, a relatively low indemnity (P_L) is paid to policyholders, while at the higher trigger a larger indemnity (P_H) is paid. Because the probability of the limited-coverage policy being triggered is significantly lower than the probability of the full-coverage policy being triggered, the cost of limited-coverage insurance would be substantially lower than that of full-coverage insurance.

Figure 2.2 Illustration of full and limited coverage weather index insurance (WII)



Source: Authors' creation, based on Lybbert and Carter (2014).

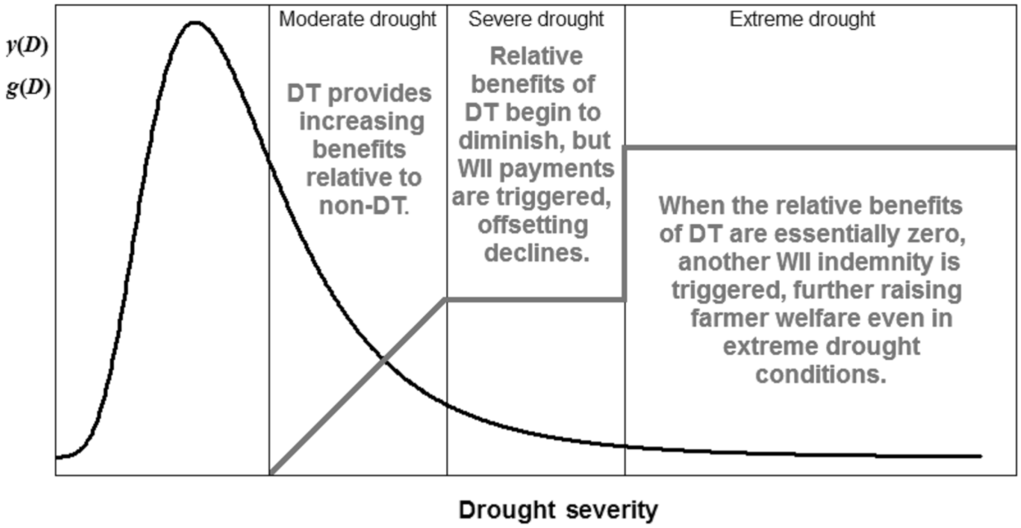
3. POTENTIAL BUNDLES OF DROUGHT-TOLERANT RICE CULTIVARS WITH WEATHER INDEX INSURANCE

Taken separately, neither improved cultivars nor index insurance is a perfect solution to the problem of covariate weather shocks. Certain DT traits in rice, for example, may provide yield benefits relative to other common varieties and protect farmers against yield loss if rainfall does not occur for several weeks during late stages of plant growth. But the traits may perform much less if drought occurs at an early stage of crop growth or if the drought is severe or extreme. Furthermore, these benefits are relative, and the improved cultivars may still suffer serious absolute yield declines under stressed conditions. Index insurance, on the other hand, may be too costly at actuarially fair prices covering both moderate and severe drought, or it may not pay out to farmers when the drought is too localized for the index to capture. For these reasons, some call for moderation in the enthusiasm to promote index insurance products in some countries and drought-tolerant cultivars in other countries without an appreciation for their respective limitations (Lybbert and Carter 2014).

The individual shortcomings of biological and financial risk management tools offer researchers, practitioners, and policymakers with unique opportunities to learn about the potential interactions between these two methods of managing drought risk. Because index insurance policies can be designed to cover extreme events that stress-tolerant crops cannot endure without significant reductions in yield, it is possible that bundling DTs with complementary insurance could result in a crowding-in effect for both. Whether or not crowding-in or crowding-out occurs is an important research question with clear policy implications. If there is crowding-out, then uptake of either tool may be limited in the presence of the other. Restructuring insurance packages to better complement DT rice could potentially diminish this crowding-out effect. If there is crowding-in, then there exists an opportunity to design novel risk management packages that include both biological and financial tools. This study aims to address these questions.

The stylized performance of a proposed DT-WII bundle is shown in Figure 3.1. As before, DT rice provides positive and increasing relative benefits under moderate drought stress conditions, but such relative benefits begin to diminish once the drought stress becomes severe. As illustrated, the WII product is structured to be initially triggered at the level of drought stress at which the relative benefits of DT rice begin to decline (that is, at point T_1). This can be thought of as limited-coverage insurance that would pay out only in severe or extreme droughts, and would therefore be significantly cheaper than full-coverage insurance products, which would have a lower trigger but would have a higher likelihood of paying indemnities. The insurance payouts help to offset the declining relative benefits of DT rice. Once the stress becomes extreme and both DT and non-DT crops fail, the insurance provides monotonically non-decreasing benefits. As illustrated in Figure 3.1, the insurance payments are based on a discrete trigger schedule (with indemnities paid out at triggers T_1 and T_2), but we note that this is merely an example of such a bundle. In this illustration, the benefits of the DT-WII bundle are non-decreasing in drought stress, which suggests that such a bundle can reduce both *ex ante* and *ex post* burdens of drought risk.

Figure 3.1 Benefits of bundled drought-tolerant (DT) seed and weather index insurance (WII) product



Source: Authors' creation, based on Lybbert and Carter (2014).

Some important issues clearly 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 increased research and breeding efforts, which can take a significant amount of time. 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 comprehensive understanding of the yield profile of the DT rice. Second, it is not necessarily a simple and straightforward matter to modify the WII to perfectly complement the DT rice: modifying the trigger at which indemnities are paid out is likely to be more complex. This complexity can be partly offset by a deeper understanding of the DT performance parameters, but the extent to which DT traits have different effects on the relationship between drought severity and yield at different levels of drought severity may imply that more than just the trigger should be changed to optimize the DT-WII bundle.

Calibrating a limited-coverage index insurance policy to complement DT rice requires consideration of three important aspects: index construction (including triggers), indemnity payments, and pricing. As discussed in the preceding section, 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. As previously mentioned, researchers have reported that production is not damaged even if there is a 14 to 21 day dry spell during reproductive stages, and only a modest reduction in yields is observed if there is no rain for three to four weeks and soil moisture is sufficient. Additionally, we have information on yields under various weather conditions for BRRI dhan 56. Under controlled irrigated conditions, BRRI dhan 56 yields 5.2 t ha^{-1}; under moderate drought stress, it yields 3.2 t ha^{-1}; and under severe drought stress, it yields 1.6 t ha^{-1}. Assuming BR 11 performs in a similar fashion to IR 64 under drought stress, yields decline with increasing stress such that the relative benefits are maximized at approximately the point where a moderate drought becomes a severe drought. The "moderate" and "severe" labels are somewhat ambiguous, but Verulkar et al. (2010) classify a drought as moderate if average yield losses in the particular trial were 30–65 percent compared to the irrigated control, while a severe drought was one in which average yield losses were 65–85 percent compared to the control.

The indemnity payments are computed as some function of the expected area value of the crop under a particular scenario. A pilot insurance program in Bogra district conducted during *aman* 2013 (prior to the implementation of this present study) offered insurance products with payouts based on actuarial calculations using data provided by the Bangladesh Bureau of Statistics. This program specified indemnities for “bad” droughts on a 10 decimal (0.1 acre) plot equal to Tk. 300, while claims on a “catastrophic” drought paid out Tk. 600 for a 10 decimal plot. These payouts corresponded to index triggers of 12- and 14-day dry spells.[7]

Since researchers 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. The low-threshold trigger used in the 2013 pilot project (that is, a 12-day dry spell) no longer makes sense for use in a complementary limited-coverage policy, because under such a specification indemnity payments would kick in when the relative benefits of BRRI dhan 56 are presumably still increasing. Due to the absence of studies comparing the performance of BRRI dhan 56 and BR 11, we cannot be certain whether 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. To be consistent with the insurance product that was previously offered to farmers as part of the 2013 pilot project, we need to specify two index triggers that each pay out different indemnities. Given that BRRI dhan 56 can withstand substantial dry spells without reductions in yield, we also need to estimate what the losses would be for a plot cultivating BRRI dhan 56 under various lengths of dry spells. Conservatively, in an attempt to take into consideration differences in yield performance on farmer fields versus test plots, we conservatively assume that BRRI dhan 56 yields start to decline after a 14-day dry spell, and therefore this becomes our low-threshold trigger that pays out Tk. 300 for a 10 decimal plot. Our high-threshold trigger is an 18-day dry spell, after which the policy pays out Tk. 600 for a 10 decimal plot.[8]

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 generally arise as the maxima or minima of underlying data-generating processes, it is appropriate to model these extrema using an extreme value distribution. There are three types of extreme value distributions, each of which is the limiting case for different types of underlying distributions. The extreme value type I distribution (also known as the Gumbel distribution), for example, arises as the limiting distribution of the maxima of normally distributed random variables. The three types of extreme value distributions can be generalized into the generalized extreme value (GEV) distribution, which can be used, for example, when one does not know the underlying distribution from which the extrema arise. The 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 given extreme events 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 $\{x_1, x_2, \ldots, x_n\}$ is

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

---

[7] 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.

[8] A decimal is a unit of land measurement commonly used in Bangladesh, equivalent to 1/100 of an acre.

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

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

Alternatively, the return level (that is, length of dry spell) associated with probability p (return period $1/p$) is

$$x_p = \hat{\xi} - \frac{\hat{\alpha}}{\hat{\kappa}}\{1 - [-\ln(1-p)]^{-1/\hat{\kappa}}\}. \tag{4}$$

Extreme value theory and extreme value distributions can be useful in the specification of WII contracts because we can use extreme value distributions to fit data and estimate the probability of extreme events occurring, which is then useful for calculating expected indemnities and actuarially fair insurance prices.

The 2013 pilot project specified a WII product based on the number of consecutive dry days during the monsoon season, drawn from 30 years' worth of daily rainfall data from a weather station in Bogra district, Rajshahi division, in northwestern Bangladesh. A GEV distribution was used to fit these data 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 perhaps a Gumbel (extreme value type I) distribution best fits these data, which furthermore 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.

An actuarially fair premium is simply the cost of insurance equal to expected indemnity payments. Consider a simple index insurance product with discrete triggers, $i = 1,2,\ldots,n$, 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 the 2013 pilot, the indemnities were 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). Then an actuarially fair price for this policy would be $A = 0.187 \times \text{Tk. } 300 + 0.098 \times \text{Tk. } 600 = \text{Tk. } 114.90$. For a limited-coverage policy 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 $\pi_2 = 0.031$), an actuarially fair price would be $A = 0.098 \times \text{Tk. } 300 + 0.031 \times \text{Tk. } 600 = \text{Tk. } 48$. Thus, as expected, the limited-coverage policy, which covers drought risk after the relative benefits of DT start to decline, would be considerably less expensive than the full-coverage policy under actuarially fair conditions.

4. EMPIRICAL APPROACH TO VALUATION OF DROUGHT-TOLERANT AND WEATHER INDEX INSURANCE PRODUCTS

To study farmers' demand for DT and WII products, both independent of each other as well as in complementary bundles, 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. In addition, choice experiments avoid the open-endedness of early contingent valuation exercises, and they are less prone to response biases and strategic behavior on the part of survey respondents (Hanley, Mourato, and Wright 2001). 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,[9] 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. 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 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.

While we can assume different decision making heuristics, 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

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

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[9] 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.

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 consumer chooses option j given all other alternatives in $\mathcal{S}$) can be written as $\text{Prob}(V_{ijt} = 1) = \text{Prob}\left(X_{ijt}'\beta + \varepsilon_{ijt} > X_{ikt}'\beta + \varepsilon_{ikt}\right) \forall k \neq j$. 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 $\mathcal{S}$ as

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

which is the basic conditional logit model of McFadden (1974) and can be estimated using maximum likelihood.

The traditional 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 $\mathcal{S}$ in choice occasion t is given by

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

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 the 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

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

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 followed that of Ward et al. (2014) by presenting the yield attribute as yields under different weather conditions. Unlike in that study, 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.[10] Instead, our approach allows for two levels of yields: one roughly corresponding to BR 11 and one roughly corresponding to BRRI dhan 56.[11]

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).

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[10] 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.

[11] 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.

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 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. 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 possible that non-certified seed could be purchased for less than that, especially if the seed were a local variety acquired from an informal source. For this reason, we have specified our lower-bound "bundle" price to be Tk. 20 per kilogram. The most expensive option would be to purchase both DT rice and full-coverage WII. It is likely that BRRI dhan 56 will be offered by BADC for about Tk. 40 per kilogram, so if this is combined with an actuarially fair full-coverage insurance product costing Tk. 115, a realistic price for this bundle is approximately Tk. 120. 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. We therefore include an additional price level in excess of this. Thus, price levels included in the choice experiment are Tk. 20, Tk. 60, Tk. 80, Tk. 120, and Tk. 150.

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 *aman* 2013). 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. 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 4.1.

Table 4.1 Summary of attributes and levels included in discrete choice experiment

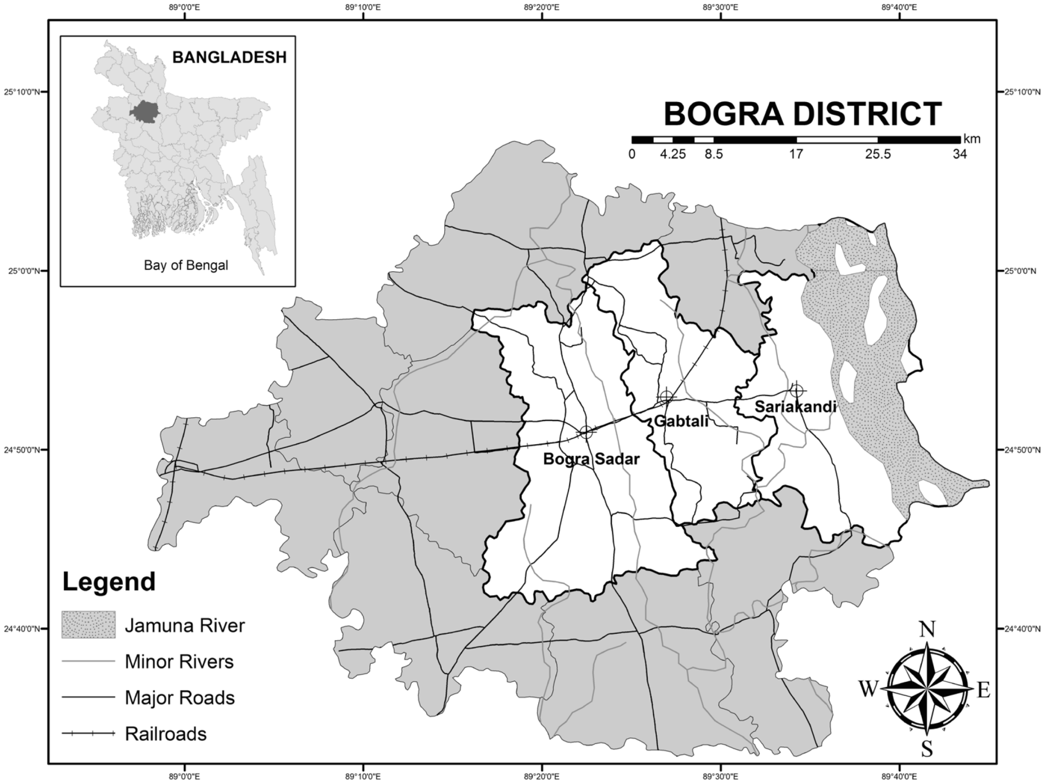
Potential yields under various weather conditions (t ha^{-1})	***Level***	***Variety***	***Normal conditions***	***Moderate drought stress***	***Severe drought stress***	***Extreme drought stress***
	1	Non-DT	6.5	2.6	1.0	0.3
	2	DT1 (BRRI dhan 56)	5.2	3.2	1.6	0.3
Duration (days from nursery to harvest)	***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.

5. STUDY AREA

The discrete choice experiment and supplementary household survey were conducted during May and June 2014 in villages in three *upazilas* (subdistricts) of Bogra district, Rajshahi division in northwestern Bangladesh, namely Bogra, Gabtali, and Sariakandi *upazilas* (Figure 5.1).[12] 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. In this study, households in 60 villages were offered WII, while the other 60 were not. Within each of the 120 villages, 20 households on average were 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*.

Figure 5.1 Bogra district, Rajshahi division, Bangladesh



Source: Authors.

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

6. RESULTS

Estimation results for the choice model using a random parameters logit specification are presented in Table 6.1. 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 6.1 are posterior mean marginal utilities and posterior mean standard deviations that are estimated via simulated maximum likelihood. Because utility is a non-cardinal measure, 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). These are reported in Table 6.2. The top panel presents the WTP estimates based on the main effects–only specification, while the bottom panel presents WTP estimates based on the regression incorporating main effects as well as interactions.

Table 6.1 Random parameters logit results

	(I)			(II)		
Parameters	Coefficient		Std. error	Coefficient		Std. 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 x Limited coverage, low trigger				0.287	*	0.155
DT rice x Limited coverage, high trigger				0.239		0.196
DT rice x Full coverage, low trigger				0.624	***	0.174
DT rice x 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	2,314			2,314		
Number of choice sets per household	5			5		
Total number of observations (N)	11,570			11,570		
Number of parameters (K)	22			22		
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 6.2 Empirical estimates of willingness to pay (WTP) for risk management tools

Main effects only			
Variable	Lower 2.5%	Mean	Upper 2.5%
WTP for drought tolerant (DT) seed	-200.45	-169.41	-142.09
WTP for short duration	158.86	184.34	212.82
WTP for medium duration	55.09	68.36	83.28
WTP for limited coverage, low trigger	107.81	135.24	166.71
WTP for limited coverage, high trigger	134.7	173.28	214.06
WTP for full coverage, low trigger	110.61	143.52	179.57
WTP for full coverage, high trigger	210	250.15	292.7
Main + interaction effects			
	Lower 2.5%	Mean	Upper 2.5%
WTP for DT rice, no insurance (main effect only)	-238.32	-198.08	-166.38
WTP for DT rice(if bundled with limited-coverage insurance)	-203.37	-137.73	-80.26
WTP for DT rice(if bundled with full-coverage insurance)	-156.22	-98.37	-50.91
WTP for short duration	148.05	172.02	201.43
WTP for medium duration	49.09	63.26	80.18
WTP for limited coverage, low trigger (main effect only)	87.32	118.32	158.06
WTP for limited coverage, high trigger (main effect only)	114.82	160.86	215.77
WTP for full coverage, low trigger (main effect only)	71.82	105.15	148.73
WTP for full coverage, high trigger (main effect only)	193.71	237.52	290.09
WTP for limited coverage, low trigger (if bundled with DT rice)	119.72	151.84	188.58
WTP for limited coverage, high trigger (if bundled with DT rice)	152.08	187.68	231.06
WTP for full coverage, low trigger (if bundled with DT rice)	144.05	178.52	217.48
WTP for full coverage, high trigger (if bundled with DT rice)	225.86	263.86	310.97

Source: Authors.

Note: 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. In the lower panel, where components are bundled together, the WTP estimates reported are for the listed component only and do not consider WTP for the other component(s) of the specified bundle.

Based on the results from the main effects–only specification, we see that there is generally a negative marginal utility associated with the DT yield distribution and 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. While this may seem relatively surprising, given that the DT rice present yield advantages over non-DT varieties during moderate and severe drought stress, it does come with a small yield penalty under normal or irrigated conditions, as detailed earlier. Given that most farmers in our sample have access to irrigation (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. What is clear, however, is 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 for 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. BRRI dhan 56 has a yield pattern similar to the DT trait illustrated here, while also being short duration. Thus, if we sum these two WTPs together, we could roughly argue that farmers would be willing to pay, on average, about Tk. 15 for seed to cultivate a 10-decimal plot of land. While this is a positive WTP, it is less than the expected market price of BRRI dhan 56, so it therefore seems unlikely that farmers would willingly adopt BRRI dhan 56 without financial incentives.

Farmers tend to highly value insurance, regardless of whether it offers full coverage or limited coverage or whether it has a low or high trigger. From these results, we estimate that farmers, on average, are willing to pay just over Tk. 300 for a limited-coverage policy and just under Tk. 400 for a full-coverage policy. These valuations are well above actuarially fair prices for these instruments (roughly Tk. 50 and Tk. 120, respectively). This is also an interesting result because farmers with access to irrigation do not really face significant risks to rice production during prolonged dry spells; they can simply pump water for irrigation as needed. In this particular context, farmers do not face additional costs as a result of any additional irrigation: more than 95 percent of the plots owned by farmers in our sample have fixed irrigation contracts with the tube well operator (typically, another farmer residing in the same area), so there is neither the incentive to reduce or delay irrigation, nor are there any extra costs associated with increased use of irrigation.[13] But simply because there are no production risks arising from dry spells does not necessarily imply that the households do not face risks of losses. Because the insurance products are based on an index, the indemnities are not tied to a specific crop and can therefore be used to compensate for any losses that might arise if the insurance is triggered, such as losses to fish or livestock, or to crops grown on plots without access to irrigation. This high WTP suggests that farmers do perceive significant risks arising from 12-, 14-, or 18-day dry spells and are willing to pay to transfer some of these risks.

We can also use these WTP estimates to assess how probable farmers perceive each of these events to be. Table 6.3 compares the actual probability of different events occurring, as well as the derived subjective probabilities based on the WTP estimates in the top panel of Table 6.2.[14] 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 is 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).

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[13] These contracts may be fixed cash payments made to the tube well owner at the beginning of the season, cash payments made at the end of the season after harvest, payments made in the form of a share of the harvest, or some combination of these payment methods.

[14] 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.

Table 6.3 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

Source: Authors.

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

The second set of results in Table 6.1 and the bottom panel of Table 6.2, which incorporate interactions between DT rice and the insurance products, reveal some interesting insights regarding the complementarities between these two risk management tools. In Table 6.2, we present WTP estimates for DT rice and the insurance components under different scenarios, which can be conceptualized as whether the component is "bundled" or "unbundled." These differ in how the binary interacting effects are treated in the partial derivatives. Rather than simply evaluating the interactions at the means, we evaluate the interactions at different levels (0 or 1) and compute the WTP under these alternative scenarios. For example, the marginal utility of the DT rice component in the unbundled case assumes that there is no insurance, so despite the positive regression coefficient associated with the interaction term, the absence of an insurance component implies that the *interaction effects* drop out and WTP is essentially calculated based on the main effect. Note that these estimates of WTP are for the components of a hypothetical bundle—not for the entire bundle. We present two bundled cases, assuming that the DT rice is bundled with a limited-coverage insurance product (with both a low trigger and a high trigger) or a full-coverage insurance product (again with both a low trigger and a high trigger). We follow a similar approach with the four insurance attribute levels (that is, presenting WTP for the insurance component bundled with DT rice and without DT rice).

First, we note that, again, the WTP for unbundled DT rice (which is computed based simply on the main effect in column II of Table 6.1, 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 Table 6.1 that 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 still negative) WTP for the DT-seed component of a DT/WII bundle reported in Table 6.2, that is, "WTP for DT rice (if bundled with limited-coverage insurance)" and "WTP for DT rice (if bundled with full-coverage insurance)." Note that even though the marginal utilities for the two high-trigger insurance payouts are statistically insignificant in Table 6.1, the WTPs for these two payouts are both statistically different from zero with a 5 percent probability of type I error. But when we consider the fact that BRRI dhan 56 is short duration as well as DT, we estimate that, on average, the WTP for the DT component approaches (in the case of being bundled with a limited-coverage insurance product) or exceeds (in the case of a full-coverage insurance product) the expected market price for BRRI dhan 56 (roughly Tk. 40).

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, while, if it were bundled with DT rice, farmers would be willing to pay nearly Tk. 340 for the insurance component. Similarly, farmers' WTP for a full-coverage insurance component increases from Tk. 342 to Tk. 442 when it is bundled with DT rice.

Clearly, 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 would be willing to pay an average of Tk. 371 for a bundle including a short-duration DT rice (similar to BRRI dhan 56) and a limited-coverage WII policy, but if, for example, the insurance were not bundled with DT rice, they would be willing to pay only about Tk. 281. This is an important result, as it 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 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.

7. 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 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 very differently. 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 assured sources of irrigation that can be used to hydrate crops during prolonged dry spells, 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 cultivars are both positive and increasing), farmers with irrigation would never likely observe these relative benefits and would 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 not related to their paddy crops, such as losses to fish or livestock, or to other monsoon-season crops grown on plots without access to irrigation. These higher valuations also suggest that farmers in our sample grossly overestimate the probabilities of these dry spells occurring. 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, WII, and DT rice + WII, our results suggest that they would prefer the bundled product. The WTP for DT rice bundled with a full-coverage policy is greater than the WTP for a limited-coverage policy, but the former bundle likely provides overlapping risk management. The WTP for DT rice bundled with a limited-coverage policy is greater than the WTP for a full-coverage policy that is not bundled with DT rice. This could provide an opportunity to “nudge” farmers into opting for the complementary bundle: farmers could be presented with a menu of risk management options including DT rice, full-coverage WII, and a bundle of DT rice + limited-coverage WII, and we would expect, on average, that most farmers would purchase the DT rice + limited-coverage WII bundle.

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 most farmers in our sample area have access to irrigation and pay for irrigation water on a fixed cost basis. 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. A large number of farmers in our sample indicated that in the absence of rain, they would typically wait around 7 days before accessing irrigation. This decision, however, was not based solely on counting the number of dry days, but rather was often based on visual cues, such as browning of the paddy 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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