Demand for complementary financial and technological tools for managing drought risk

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February 20, 2018

Abstract. Innovations that mitigate weather-related production risks can potentially benefit farmers in risk-prone areas. We examine two distinct tools for managing drought risk: weather index insurance and a drought-tolerant rice variety. Although these tools can independently address drought risk, we demonstrate the additional benefits gained by bundling them into a complementary product. Results suggest 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. We 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

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.

There are many strategies for addressing drought risks, including both ex post interventions such as emergency food aid after a drought has occurred as well as ex ante actions that mitigate or transfer drought risks in anticipation of their occurrence. 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 out in the event that certain levels of drought stress occur. Lybbert and Carter (2015) demonstrated that, while both tools address drought risk, they do so in very different and imperfect ways. DT crop varieties can reduce drought risk, but may only do so in a non-monotonic fashion (see also Lybbert and Bell 2010), perhaps only providing optimal relative benefits (vis-à-vis non-DT varieties) during moderate or severe drought conditions.[1] WII can be structured to provide monotonic benefits, but these insurance products are typically too costly for many farmers in developing countries, despite often being considerably less expensive than traditional, multiple peril crop insurance products. Yet despite these imperfections, Lybbert and Carter (2015) demonstrate how these two instruments can be combined to form a fairly comprehensive and complementary risk management tool that can, in many ways, overcome the shortcomings of each product in isolation. While not explicitly demonstrating how a WII product

[1] In what follows, we will assume three levels of drought severity, with the labels applied to these levels arising from the performance of DT varieties vis-à-vis non-DT varieties. During moderate droughts, DT varieties confer a yield advantage vis-à-vis non-DT varieties that is both positive and increasing. During severe droughts, DT varieties still confer a positive yield advantages relative to non-DT varieties, but the advantages are decreasing and the yield gap narrowing. During extreme droughts, the yield advantage has been exhausted, and DT varieties perform essentially the same as non-DT varieties.

could be calibrated and optimized to the performance of the DT variety, they are able to demonstrate how stylized insurance and bundled products yield benefits exceeding those of either a DT maize variety or a standalone insurance product, thus resulting in both higher mean farm incomes as well as risk reduction.

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 (2015), we explicitly illustrate how a drought index insurance policy can be calibrated to complement the performance of a 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 lowers the cost of the resulting insurance component, providing an additional incentive for 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.

The remainder of the paper is organized as follows. In Section 2, we provide some background on drought risk in agriculture, specifically in the context of rice production in Bangladesh. In Section 3, we discuss the benefits and shortcomings of both drought-tolerant rice and weather index insurance. In Section 4, we introduce the complementary bundled product, and demonstrate the calibration of the insurance component to the performance profile of the drought-tolerant rice variety. In Section 5, we discuss the empirical methods used in studying Bangladeshi farmers' preferences for these risk management tools. In Section 6, we discuss the experimental design and introduce the primary data used in this analysis. In Section 7, we report the results from the discrete choice experiment and unpack heterogeneity in farmer preferences. Finally, in Section 8, we offer some concluding comments and discuss the policy implications of our findings.

2. Drought risk in the context of rice production in Bangladesh

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.

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 once 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, thereby reducing 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 may not be the most pressing burdens that households face as a result of drought risk. Lybbert and Carter (2015, 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 portfolio or income smoothing effect and the more obvious ex post effects of production losses and asset depletion described above, or what Morduch (1995) referred to as "income smoothing" versus "consumption smoothing" actions. The ex ante actions that households take to mitigate drought risk involve inherently behavioral actions, where precautionary, income-smoothing actions are taken in anticipation of a shock that may or may not ever materialize. This contrasts with the ex post responses that entail what might be conceptualized as more or less economic responses, resulting in the depletion of human, physical or social capital after a negative shock has occurred, thus allowing a household to smooth consumption (Dercon, 2004). By inducing precautionary behaviors, drought risk affects the household's long-term growth trajectory, which further inhibits the households' ability to accumulate asset stocks that could be used in ex post responses against these shocks in the future. Elbers et al. (2007) analyze the effects of ex ante and ex post actions 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 on capital accumulation is not surprising, their finding that the total effect is dominated by the ex ante effects draws attention to this distinction. Even in the absence of an ex post effect (i.e., the actual losses to households' livestock holdings), the ex ante risk effect results in long-run capital accumulation 46 percent lower than under a risk-free scenario. These ex ante effects lower the household long-term growth trajectory, trapping them in a vicious cycle of poverty (Barnett et al. 2008).

In many rural settings in developing countries, 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). In numerous studies cited in the review by Dercon (2005), there is evidence that such mechanisms provide only partial risk sharing, and furthermore are largely only effective against idiosyncratic – rather than covariate – risks. Formal credit or insurance could theoretically be introduced to manage both idiosyncratic as well as covariate risks, but the glaring absence of such institutions in many rural settings is evidence that competitive financial markets fail to bring about an efficient allocation of rural finance on a purely commercial basis (Besley 1994). In many instances, more formal markets and institutions for addressing agricultural risks have failed to emerge due to a myriad of complex geographic and institutional factors, including imperfect information as well as poorly functioning or prohibitively expensive legal enforcement mechanisms. Importantly for the insurance market, asymmetric information results in externalities that constrain market efficiency, since they implicitly or explicitly increase the transaction costs to providers of formal credit or risk management.[2] In the absence of formal drought risk management, a case is often made for government intervention to provide public insurance or to subsidize insurance by the private sector. Indeed, Greenwald and Stiglitz (1986) demonstrated that constrained Pareto improvements can be attained through the government actively intervening in markets that are susceptible to imperfections or information asymmetries. But arguably, governments themselves lack the perfect information with which to effectively design or target such interventions (Roumasset 2006), and furthermore, where they have been attempted, the costs of such programs have been substantial, and often prove to be an economically and fiscally inefficient use of scarce public resources (Wright 2014).[3] Yet the fact remains that in the absence of adequate risk management – formal or informal – large numbers of farmers in developing countries are 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.

3. 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-

[2] It should be noted, however, that an increase in transaction costs is not a necessary condition for increased inefficiency. We are grateful to an anonymous reviewer for highlighting this point.

[3] Additionally, Roumasset (2006) has also suggested that subsidized crop insurance will also partially displace risk-reducing strategies and risk-coping strategies, which in turn will increase the excess burden.

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.[4] 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.[5] 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.[6]

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 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 exhibits a quasi-insurance characteristic.[7] 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

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

[5] 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.

[6] 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.

[7] As an illustrative example of the quasi-insurance functionality of stress-tolerance, a recent study by Emerick et al. (2016) has even shown how the introduction of a stress-tolerant rice variety (specifically a submergence-tolerant variety) in eastern India leads to a crowding-in of investments in modern inputs – similar to what might be expected from an actual financial insurance product – and an overall increase in agricultural productivity above and beyond simply reducing production risk.

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. This perception can be particularly pronounced in situations in which farmers cultivating the DT variety sacrifice expected yield for a reduction in risk. Because of variations in soil and environmental conditions and heterogeneity in phenotype-environment interactions, however, the "terms" of the quasi-insurance (i.e., the full economic costs of the quasi-insurance characteristics and the conditions under which benefits are realized) are essentially concealed from the farmer. Furthermore, these "terms" are incredibly difficult for farmers to learn, even with repeated experiences with the DT under various conditions. This likely mutes any changes in farmer behavior that might accrue from reduced exposure to production risks, such as increased investments in higher risk agricultural inputs.

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

According to the conventional view, risk averse farmers faced with either production or price uncertainty tend to underinvest in modern technologies that are (correctly or incorrectly) viewed as risky (e.g., Bardhan and Udry 1999).[8] According to this view, then, providing insurance to transfer some of the risk away from the farmers would, in theory, result in increased use of modern inputs that would, on average, increase productivity and improve rural livelihoods. This consideration was often used as justification for subsidizing crop insurance (Roumasset 2006). But in many cases (in both developed as well as developing countries), traditional, multiple peril crop insurance is proving to be an idea that is perhaps good in theory, yet poor in practice (Hazell 1992; Skees, Hazell, and Miranda 1999; Smith and Watts 2009).[9] Consistent with these experiences, multiple peril crop insurance has seen limited success in Bangladesh. Traditional crop insurance has many well-known problems (Hazell et al. 1986; Binswanger 2012). First, the

[8] Quiggin (1992) has demonstrated that, for risk-averse producers, insurance will reduce the demand for inputs that are risk-reducing or risk-constant, but will increase demand for inputs that are strongly risk-increasing (marginal product is unambiguously non-positive under 'bad' states of the world), although the effect of insurance on demand for inputs that are weakly risk-increasing (marginal product under 'good' states exceeds the marginal product under 'bad' states) is ambiguous. This has led other researchers (Roumasset 2006) to point to insurance as resulting in positive and negative negligence: negative negligence is the tendency to reduce the use of risk-reducing inputs (e.g., pesticides), while positive negligence is the tendency to excessively apply inputs that have positive marginal products only in 'good' states. Whether these effects have an impact on farmer livelihoods depends crucially on the degree of risk aversion and the probability and potential impacts of 'bad' states.

[9] Some authors (e.g., Roumasset 2006) would go further and argue that insurance is bad in practice because it is bad in theory, and argue that the time has come to explore more promising approaches to managing agricultural risks.

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 (Miranda and Farrin 2012; Smith and Glauber 2012; Wright 2014).[10] Additionally, there are potentially 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 a promising 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, payments are based on index strike points 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 severity 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 payments to be calculated easily and potentially distributed in a timely manner (Turvey 2002). Additionally, because insurance payments are based on an index rather than loss adjustments calculated for each farm that is insured, operating and administrative costs may be significantly lower than those of other types of agricultural insurance (Barnett, Barrett, and Skees 2008).[11] Along the same lines, contracts can be standardized and need not be tailored to the individual needs of different policyholders (Skees 2008). Finally, because the index strike points are independently measured and easily verifiable,

[10] Here, and in what follows, we will use the term 'administrative' costs (or loads) to refer to all costs above and beyond expected indemnities related to the administration and operation of the insurance program, including costs associated with reinsurance.

[11] In this discussion, we have treated information asymmetries and administrative costs as two separate problems. Certainly, there is a case to be made that some portion of overall administrative costs in traditional, multiple peril crop insurance programs are directly attributable to on-farm assessments of losses, which are, in many ways, aimed at minimizing such asymmetries (particularly moral hazard). Wright (2014) has estimated that administration, adjustment, and reinsurance costs for multiple peril crop insurance programs in the US to amount to between 30 and 40 percent of indemnities. Smith and Watts (2009) are less optimistic about the potential for index insurance to significantly reduce administrative costs, suggesting that, even for an index insurance product in which there would be no need for on-farm assessments, administrative costs are "likely to amount to at least 25 to 30 percent of the actuarially fair premium rate," though it is unclear exactly from where this estimate was derived.

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 been 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 payments are based on an index constructed from observed weather variables, the extent of basis risk is in many ways endogenous, depending upon the number and geographic disparity of weather stations at which weather variables are measured, the number of weather variables included in the index, and the strength of the relationship between the weather variables and the outcomes that the insurance product purports to provide risk management against. Nevertheless, because insurance payouts are not determined based on on-farm assessments, there is a nontrivial probability that an insured farmer 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.[12]

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). In practice, this is far more complex that it may initially sound. One would ideally want to estimate production losses that would occur under various weather conditions relative to a baseline avoiding moral hazard. There is evidence suggesting relatively low correlations between yields and weather variables on which most index-based insurance products are based (Rosenzweig and Binswanger 1993). Smith and Watts (2009), for example, 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

[12] 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 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.

(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.

For the purposes of this research, we have followed the somewhat traditional practice of basing our index on rainfall measurements, which are then converted into a measure of dry days, which are then aggregated to dry spells. This indexing strategy is not entirely satisfying, since there are likely many other variables that would condition farm production and full income losses, and certainly continued research is needed to improve and refine weather indexing to provide the greatest value to farmers. Since one of our primary motivations in the current research is to demonstrate the feasibility and assess the potential market viability of a bundled product consisting of a DT variety and a specially-calibrated WII product, we had to opt for a simplified index that necessarily ignored the potential impacts of these other weather variables. As will be demonstrated in greater detail below, the calibration requires some specific knowledge regarding the performance profile of the DT variety, specifically under a range of weather conditions. Since the variety in question is relatively new, there is rather limited information in this regard. One specific performance characteristic that is known is its ability to withstand prolonged periods without rainfall, and as such this seemed an ideal – though perhaps unrealistically simplistic – weather variable on which to base the complementary WII product. More complex indexes could have been constructed, but such indexes would not have been optimized to match the profile of the DT variety.

4. 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 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 2015).[13] A bundled DT-WII product, for example, could provide monotonically increasing (or at least 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.

[13] For a graphical depiction of the benefits of DT (vis-à-vis non-DT varieties), WII, and DT-WII at various drought intensities, the interested reader is directed to Figure 22.2 in Lybbert and Carter (2015, p. 409).

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 (2015), who helpfully demonstrate how a stylistic DT-WII product might be structured. While an independent, "full coverage" index insurance product could be structured to pay out to policyholders 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 payments under severe droughts that compensate farmers for the declining relative benefits of the DT under such conditions.

Some important issues surround the bundling of a DT-WII package. First, the bundle's two components have significantly different benefit profiles. Insurance 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 strike points), insurance payouts, 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 relative 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.[14] 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

[14] 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).

high-threshold trigger is an 18-day dry spell.[15] 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 and the Bangladesh Meteorological Department. The pilot specified payments for moderate droughts on a 10 decimal (0.1 acre) plot equal to BDT 300, while claims on a severe drought paid out BDT 600 for a 10 decimal plot, corresponding to index strike points of 12- and 14-day dry spells, respectively.[16,17] Like Lybbert and Carter (2015), 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 benefit profile, such that the same payments (BDT 300 and BDT 600) now correspond to higher strike points (14-day and 18-day dry spells, respectively).

The actuarially fair cost of insurance is a function of both the probability that index strike points are triggered and the corresponding payments that will be made in such instances. In what follows, we will demonstrate a straightforward method for calculating the probability of weather extremes using Extreme Value Theory (EVT).[18] 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. Specifically, the insurance was designed to pay out depending on the longest dry spell that occurred during the monsoon season. This maximum arises from an underlying distribution of a series of dry spells of varying lengths that have occurred during a given season. According to EVT, then, we can model these longest dry spells as arising from a generalized extreme value (GEV) distribution, with cumulative distribution function (CDF) taking the form

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

where x is some datum (in our specific case, the annual maximum dry-spell), $\xi \in \mathbb{R}$ 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 particular extreme events occurring.[19] 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

[15] While the present index is based solely on dry days, with more evidence on the performance of BRRI dhan 56 under various weather conditions, it should be possible to incorporate other variables into a complementary insurance index, such as temperature, wind speed, etc., such that the index could be a multidimensional crop growth index that takes into consideration nonlinear yield responses and weather variable interactions.

[16] 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.

[17] At the time of the study, one BDT was equivalent to 0.013 USD (or approximately 78 BDT per USD).

[18] While EVT is not frequently used within the broad economics community, there are examples of EVT being used within the risk management community (e.g., Diebold et al. 2000) and specifically with respect to agricultural risk management (e.g. Manfredo and Leuthold 1999).

[19] The terms "return level" and "return period" are intimately related concepts that are central to extreme value theory. The return period is an estimate of the expected interval between occurrences of an event of a given magnitude, and is calculated as simply the inverse of the probability of said event occurring during any given year.

$$\ln[L(\xi,\alpha,\kappa|x) = \sum_{i=1}^{n}\left\{-\ln\alpha - \left(1+\frac{1}{\kappa}\right)\ln\left[1+\kappa\left(\frac{x_i-\xi}{\alpha}\right)\right] - \left[1+\kappa\left(\frac{x_i-\xi}{\alpha}\right)\right]^{-\frac{1}{\kappa}}\right\}.^{20} \quad (2)$$

To examine drought risk in Bangladesh, we rely on 30 years' worth of daily monsoon rainfall measurements from the Bogra district weather station to identify the sequence of annual maximum dry spells.[21] We then use maximum likelihood techniques to estimate the location, scale, and shape parameters characterizing the distribution. Specifically, we estimated a location parameter $\hat{\xi} = 8.24\ (0.43)$, scale parameter $\hat{\alpha} = 2.09\ (0.33)$, and shape parameter $\hat{\kappa} = 0.17\ (0.15)$. With these parameter estimates, we can then estimate either the probability p of event x_p occurring or determine what event x_p will occur with probability p. For example, an estimate for the probability of annual maximum dry spell of at least x_p can be written as

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

This estimated probability is important because actuarially fair insurance is priced such that the cost of insurance equals the expected payout received. Consider a simple index insurance product with discrete strike points, $i = 1, \dots, n$ corresponding to different mutually exclusive drought events, and let p_i define the probability of strike point i being triggered. Let I_i be the insurance payout under strike point i. Then an actuarially fair premium would be $A = \sum_{i=1}^{n} p_i I_i$. For example, for a full-coverage policy (like the policy offered during the 2013 pilot), the insurance payout would be BDT 300 (I_1) for a 12-day dry spell (p_1=0.187) and BDT 600 (I_2) for a 14-day dry spell (p_2=0.098), for which the actuarially fair cost of insurance would be $A = 0.187 \times \text{BDT } 300 + 0.098 \times \text{BDT } 600 = \text{BDT } 114.90$. For a limited-coverage policy complementing the DT variety, but making the same payments (that is, BDT 300 and 600) after 14- and 18-day dry spells, respectively (with $p_1 = 0.098$ and $p_2 = 0.031$), the actuarially fair cost of insurance would be $A = 0.098 \times \text{BDT } 300 + 0.031 \times \text{BDT } 600 = \text{BDT } 48$.

The limited-coverage policy would be considerably less expensive than the full-coverage policy under actuarially fair conditions. This illustrates how the DT component reduces the cost of risk management. In this case, insurance is nearly BDT 67 cheaper than it would be without DT, representing a substantial 58 percent reduction in the actuarially fair cost of insuring farm income losses from drought. This does not even consider the fact that bundling the DT with WII

For example, the return period for a '100-year flood' would be simply 100 years (with associated annual probability of 0.01). The return level is an estimate of the magnitude of the event that would occur with a given return period or probability. In the case of a '100-year flood', the return level might be some measure of the streamflow that would be expected with probability 0.01.

[20] Admittedly, the assumption of independence may be strong in some contexts. For the purposes of our hypothetical preference elicitation exercise, we maintain the assumption of independence and note that model diagnostics support this assumption. For actual implementation of a program such as this, concerns over independence could be ameliorated by introducing a more general model specification that would allow for local temporal dependence (a rigorous treatment can be found in Leadbetter et al., 1983).

[21] Ideally, one would like to avail rainfall data at the highest possible spatial resolution in order to reduce basis risk associated with disparities in rainfall conditions between farmer fields and the weather station where index measurements are recorded. In taking a program like this to scale, one might like to avail upazila-level rainfall measurements, or, at the least, use district-level rainfall measurements and use spatial interpolation methods to estimate rainfall measurements at lower levels of spatial aggregation.

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 on top of the actuarially fair cost. 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 (not to mention most neoclassical economists' disdain for subsidies), this implicit reduction in insurance costs may be a powerful tool for providing the incentives necessary to promote widespread adoption of the DT-WII risk management product.[22]

5. Empirical Approach to Valuation of DT and WII Products

To study farmers' preferences toward DT and WII products, both independently as well as in a bundled product, we employ discrete choice experiments. 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.[23] 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.

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 task 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 task t. For a fixed budget constraint, individual i will choose alternative j so long as $V_{ijt}^{*} > V_{ikt}^{*}\ \forall k \neq j$.

We assume that indirect utility is linear in the parameters, though through incorporating interaction effects, we allow for some nonlinear marginal utilities. We can therefore write individual i's utility function as

[22] 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."

[23] 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.

$$V_{ijt}^{*} = X_{ijt}^{'}\beta_i + \varepsilon_{ijt}, \tag{4}$$

where $X_{ijt}^{'}$ is a vector of attributes for the j^{th} alternative, $\beta_i \sim f(\beta|\Omega)$ is a vector of individual-specific taste parameters (that is, a vector of preference 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 (Gumbel) distribution. This stochastic component of utility captures unobserved variations in tastes as well as errors in the individual's perceptions and optimization. The vector Ω defines the parameters characterizing the distributions of the preferences within the population. For example, if β is multivariate-normally distributed in the population, then Ω would represent a matrix of means and variances. These distributions capture heterogeneity in tastes and preferences for different individuals within the population.

We do not directly observe V_{ijt}^{*}, but instead observe the sequence of choices $y_i = (y_{i1}, \dots, y_{iT})$, where y_{it} is the choice that maximizes individual i's utility in choice task t. The probability of individual i's observed sequence of choices is given by

$$\text{Prob}\left(y_i | X_i^{'}, \Omega\right) = \int \frac{\exp\left[X_{iy_{it}t}^{'}\beta_i\right]}{\sum_{k=1}^{K} \exp\left[X_{ikt}^{'}\beta_i\right]} f(\beta|\Omega)\, d\beta, \tag{5}$$

This is the mixed (or random parameters) logit model (Revelt and Train 1998; Train 2003). The mixed logit is regarded as a highly flexible model that can approximate any random utility model and relaxes the limitations of the traditional conditional logit by allowing random taste variation within a sample according to a specified distribution (McFadden and Train 2000). Because the integral in equation (5) will not generally have a closed form, the probability can be approximated numerically through maximum simulated likelihood.

Estimation of the mixed logit model given by equation (5) generates a series of estimated distributions for preferences in the population. Specifically, estimation yields a series of population moments (e.g., mean and variance) that characterize the level and dispersion of preferences within the population. On its own, however, estimation of equation (5) does not yield any information regarding the preferences for any particular member of the sample. Sometimes, it may be valuable to understand where in a particular distribution of tastes and preferences a particular individual may lie. Using the population distributions in conjunction with individuals' observed choices over different choice tasks, it is possible to derive a distribution of each individual's preferences. These distributions represent an estimate of individual-specific preferences, conditional upon observed choices and the distribution of tastes in the population (Revelt and Train 2000; Train 2003).[24]

Ultimately, our objective in this study is 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-

[24] It is perhaps a misnomer to refer to these conditional estimates as "individual-specific," since the conditional distribution is more appropriately the distribution of tastes for the subpopulation that responds in a similar fashion when presented with the same choice scenario (Train, 2003).

WII product. Given the utilitarian interpretation of our econometric specification, the vector of parameters $\beta = (\beta_{i1}, \beta_{i2}, \ldots, \beta_{iP})$ defining tastes and preferences over the various 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 β_{iP} can be interpreted as the marginal (dis-) utility of product price, and assuming this value is negative, and 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.[25] 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

$$\mathrm{WTP}_{ij} = -\frac{\partial V_i / \partial X_{ij}}{\partial V_i / \partial X_{iP}} = -\frac{\beta_{ij}}{\beta_{iP}}, j \neq P, \tag{6}$$

where β_{ij} is the estimated parameter for the j^{th} attribute for individual i. In this expression, both β_{ij} and β_{iP} are random. Since WTP is the ratio of two random variables, WTP has a probability distribution of its own. We will therefore be interested in both the mean and the variance of individuals' WTP for the different bundle components. The marginal WTP for favorable (unfavorable) attributes will be positive (negative). 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.

Operationalizing estimation of equation (5) requires some specification. Specifically, we must specify the family of distributions from which each of the random parameters are drawn. Typically, researchers allow for most parameters to be distributed normally. This has intuitive appeal, but, since the domain of the normal distribution is infinite, it introduces the possibility of extreme values, which can exert excessive influence on the population distributions and calculations of WTP. In our empirical application, we allow all non-price preferences to be distributed according to a truncated normal distribution: $\beta_{ij} = \beta_j + \sigma_j \nu_{ij}$, where ν_{ij} is mean-zero and normally distributed on (-1.96, 1.96). This maintains the intuitive appeal of normally distributed preferences in the population, while imposing some moderate restrictions on parameter space for the underlying empirical distribution.

Specifying the distribution of the price parameter requires some careful consideration. Allowing the price coefficient to be distributed normally is problematic for several reasons. First, since the normal distribution is symmetric around zero, some individuals in the sample would be determined to have positive marginal utilities for the bundle price. To be consistent with microeconomic theory, individuals' marginal utility of price should be negative, yielding downward sloping demand curves. Second, since WTP is calculated as the ratio of one random coefficient to the random coefficient associated with price, the resulting distribution of WTP would be the ratio of two normally distributed random variables. WTP would therefore take a

[25] There are valid theoretical grounds, particularly from within the behavioral economics literature (e.g., Rabid and Thaler 2001), to suggest that the marginal utility of income is not monotonic, so using the marginal disutility of price (which enters linearly into our specified utility function) as a proxy for the negative marginal utility of income may not be ideal. However, since the marginal disutility (utility) of price (income) enters as the denominator in our estimate of WTP in equation (8), we have to make some simplifying assumptions in order to ensure that the distribution of the marginal disutilities (utilities) is such that the distribution of WTP has defined and finite moments. This issue is discussed in greater detail below.

Cauchy distribution, which has an infinite variance. Historically, when researchers have faced these challenges, they have simply assumed that the price coefficient is constant (e.g., Revelt and Train 1998). This is analogous to assuming that preferences over prices are homogeneous in the population. This does not guarantee that the price coefficient will be negative, but does yield advantages. Notably, the distribution on the derived attribute WTP is the same as the distribution of the random attribute coefficient, with the mean and variance scaled by the price coefficient (Hensher, Rose, and Greene 2006; Revelt and Train 1998; Ubilava and Foster 2009). But while this may introduce some advantages, it also introduces the distinct disadvantage of a lack of realism. If we believe that individuals' preferences vary over all of the other bundle attributes, why should we not believe that individuals' preferences over money vary as well?

To restrict the sign of the price coefficient, we can specify a distribution whose domain lies completely on one side of zero. Traditionally, researchers have allowed the (negative) price coefficient to be distributed lognormally. This has the appeal of restricting the sign of the coefficient, but the fat tails of the lognormal distribution can result in an increased probability of extreme coefficients, which can yield unreasonable estimates for WTP. Furthermore, since the lognormal distribution is the distribution of a random variable whose logarithm is normally distributed, the resulting ratio distribution characterizing WTP will have an infinite variance. For our application, we allow the (negative) price coefficient to take a one-sided triangular distribution: $\beta_{iP} = \beta_P + \beta_P \nu_{iP}$, where ν_{iP} has a triangular distribution with limits (-1,1). This assumption yields the intuitive result that the marginal utility of income (marginal disutility of price) is positive (negative), while also restricting $\beta_{iP} \in [-2\beta_P, 0]$. Additionally, under this assumption, WTP is no longer the ratio of two normally distributed random variables, and so will have a finite variance[26].We can approximate the mean and variance WTP by taking first-order Taylor Series approximations around the population means, which are the posterior mean estimates that result from estimating equation (5).

6. Experimental design and data sources

For this 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 (see Table 1). 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.[27] Instead, our

[26] Recent advancements in choice modeling allow for model estimation directly in WTP-space (Scarpa et al. 2008), however, we encountered computational challenges associated with estimating such models with a large number of observations.

[27] At the time of writing, 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 utilize the reported yield levels under stress conditions reported in Verulkar et al. 2010.

approach allows for two levels of yields: one roughly corresponding to BR 11 and one roughly corresponding to BRRI dhan 56.[28]

[Table 1 Approximately Here]

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 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 combining an index trigger and corresponding payment: no insurance, a policy paying BDT 300 after a 12-day dry spell ("full coverage, low trigger"), a policy paying BDT 300 after a 14-day dry spell ("limited coverage, low trigger"), a policy paying BDT 600 after a 14-day dry spell ("full coverage, high trigger"), and a policy paying BDT 600 after an 18-day dry spell ("limited coverage, high trigger"). While we did not explicitly quantify the degree of basis risk that farmers would be exposed to, farmers were explicitly informed that the insurance product would pay based upon rainfall measured at the Bogra district meteorological station and that the weather conditions at this station were not necessarily going to be the same as the conditions on their farm.

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

[28] 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 (reported in Verulkar et al. 2010). In that study, an event was classified 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.

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 BDT 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 BDT 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 BDT 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 BDT 115 would yield a realistic price for the bundle at approximately BDT 150, which we set as the upper-bound price in our choice scenarios. Thus, price levels included in the choice experiment are BDT 20, BDT 60, BDT 80, BDT 120, and BDT 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.

An important caveat that must be addressed is that we do not explicitly allow for preferences to be influenced by the existence or extent of basis risk. Since our choice experiment was conducted among a sample of farmers with limited experience of index insurance, and hence an imperfect understanding of the terms of the insurance portion of the bundled risk management product, it may certainly be the case that farmers state preferences under the false assumption that the insurance product would pay out under all moderate or extreme drought conditions. If this is the case, then the marginal disutility of basis risk would not be fully accounted for, and thus the total WTP for the index insurance component could be biased upward.

For the choice experiment, we present farmers with a series of choice tasks, each including two hypothetical seed/insurance bundles or alternatives 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).[29] We specified a blocked D-optimal design using a modified Federov algorithm with a full-factorial candidate set, eliminating any candidate sets in which one option clearly dominated the other.[30] 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. Our design specification results in 30 choice tasks, which were blocked so that each farmer only evaluated 5 choice tasks (6 blocks), reducing

[29] As part of the script introducing the choice experiment, participants were urged to respond to choice tasks truthfully and to make decisions consistent with those they would make under real world conditions. While these efforts mitigated hypothetical bias, it is not certain that such biases were eliminated.

[30] 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.

the incidence of respondent fatigue during the exercise. A sample choice task is presented in Figure 1. In this particular scenario a farmer was asked to evaluate and choose between option A which is comprised of a long duration non-DT seed bundled with a full coverage-high trigger insurance product for BDT 150, option B which is a short duration DT variety bundled with a limited coverage-low trigger product for BDT 120, or option C the status-quo. The choice tasks were translated to Bangla for field implementation.

[Figure 1 Approximately Here]

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 2).[31] Bogra district lies in Rajshahi division in northwestern Bangladesh. The sample is largely comprised of households that were interviewed for the 2013 pilot study. In that study, insurance products were marketed to members of a local Nongovernmental Organization (NGO), Gram Unnayan Karma (GUK), which operates largely as a microfinance institution through its extensive network of village-level women's groups. In the 2013 pilot, 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 GUK's rosters. While our original intent for the present study 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 members of the local GUK group. Our ultimate sample consisted of 2,314 households across the three *upazilas*.

[Figure 2 Approximately Here]

Table 2 presents some average characteristics for the households in our sample. While GUK primarily works with women's groups, the vast majority of households are headed by males. Since almost all of the participants in the choice experiment were the household heads, this implies that most respondents were males. Households in the sample are relatively young, with the average age of the household head only 43 years of age. Household heads are split between literate (49 percent can read and write) and mostly illiterate (16 percent can neither read nor write, while an additional 35 percent can only sign their name). Formal savings remains relatively sparse, with only about 30 percent of households having a savings account. Most farmers in the sample rely on informal savings mechanisms, either relying upon informal savings groups (20 percent) or savings boxes at home (30 percent). But despite the limited formal savings, most respondents indicate that they have enough savings to meet at least their basic consumption needs, with 46 percent indicating that they had "more than enough" savings. While formal savings may be relatively sparse, households in the sample do generally have experience with credit, which is not surprising given their association with GUK and GUK's primary activities. There are a few households that have previously purchased weather or crop insurance from the government or a private company (12 percent), while almost 15 percent of respondents know someone who has purchased insurance from the government or a private company.

[Table 2 Approximately Here]

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

7. Results

Estimation results for the choice model using a mixed logit specification are presented in Table 3. The estimates reported here are posterior mean marginal utilities and posterior mean standard deviations that are estimated via maximum simulated likelihood. In this table we present the results from three different model specifications (of increasing generality) for the underlying random utility model. The first set of results is derived from a main effects-only utility specification, assuming a constant price coefficient. This model allows for heterogeneous preferences with respect to the DT characteristic, duration, and insurance, but assumes that everyone in the population has the same preferences toward the price. This is the most restrictive of the models we consider, but also represents what would traditionally be considered a suitable specification, given other concerns about computational complexity and the ability to derive finite moments for the distribution of WTP. The second set of results is more general, relaxing the assumption of a fixed price coefficient and allowing for heterogeneous preferences with respect to price (following the one-sided triangular distribution described above), while still only permitting main effects. Both of these first two sets of results assume that preferences for DT do not depend upon whether the DT is bundled with insurance, and vice versa. Like the second set of results, the third set of results allows for random price preference variation, but now relaxes this latter assumption and incorporates interactions between the DT attribute and the four insurance attributes.

[Table 3 Approximately Here]

Several observations emerge as we move from column (I) to column (II) to column (III). Across all specifications, the expected value (posterior mean) of most of the marginal utility coefficients is statistically different from zero, though many of the distributions demonstrate significant dispersion. Furthermore, most of the posterior mean marginal utilities remain largely the same, regardless of the model specification. When it comes to seed characteristics, farmers typically do not prefer the DT trait (i.e., the series of possible yields under alternative weather/rainfall conditions that would be conferred by BRRI dhan 56), while they do prefer increasingly shorter durations. The expected value of the marginal (dis-)utility of price (or, more appropriately, the marginal utility of income) increases when it is allowed to vary, and the marginal utility of income and the marginal utility of DT change (both increase in absolute value) under specification (III) once the DT trait is interacted with the different insurance attributes. The positive interaction terms—though not all statistically different from zero—suggest that utility of DT is marginally increasing if the DT seed is bundled alongside an index insurance, and the utility of index insurance contracts is marginally increasing if it is bundled alongside DT. As we will discuss below, this key finding suggests potentially powerful complementarities between these two innovations for managing drought risk.

From standard regression diagnostic tools (log-likelihood function value, McFadden's adjusted pseudo-R^2, Akaike and Bayesian information criteria), we determine that the third model is marginally superior to the other models. We will focus on these results as the basis for discussions that follow. Figure 3 illustrates the estimated distributions of preferences for the different choice attribute and interaction effects. These densities are based on the preferences for a simulated population of 100,000 heterogeneous respondents, with each simulated respondent's preferences drawn from a distribution of the specified family with the estimated posterior moments reported in column (III) of Table 3. The grey shaded areas represent 95 percent confidence intervals for the mean marginal utility coefficient associated with each of the attributes or interactions. For most preferences, the mean is statistically different from zero with at most a 5 percent probability of Type I error, though some of the interaction effects have slightly lower levels of statistical significance. For the limited coverage/low trigger and full coverage/low trigger distributions, the posterior estimate for the standard deviation of preferences was not statistically different from zero, which essentially implies that preferences for these two product attributes are nearly constant in the population. With such narrow distributions due to such little variation in preferences, we are quite confident that almost all farmers' preferences will be statistically indistinguishable from the average. Similar stories emerge—though less dramatic—for preferences for other attributes or coefficients corresponding to interaction terms.

[Figure 3 Approximately Here]

Since these results relate to marginal utilities, they are not easily interpretable beyond providing information on preference rankings. It is often more informative to examine the monetary valuations of these traits achieved by calculating the expected marginal WTP based on equation (6). Table 4 reports estimates of the sample average (unconditional) marginal WTP for a select set of risk management products based on the estimates in Table 3 along with corresponding 95 percent confidence intervals. 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. As previously discussed, since the underlying preferences that are used to compute WTP are random, the resulting WTP takes a ratio distribution, with $E\left[\mathrm{WTP}_j\right] = E[\beta_j]/E[\beta_P]$ and $\mathrm{Var}\left[WTP_j\right] = (E[\beta_j]^2 + \sigma_j{}^2)/E[\beta_P]^2$. Since some of these product bundles are sums of WTP for individual components, the resulting expected WTP is simply the sum of the expected WTP for the individual components, with the variance equal to the sum of the variances for the individual components.[32]

[Table 4 Approximately Here]

As expected from Table 3, we see in Table 4 that there is generally a negative WTP for the yield distribution conferred by the DT technology (though, admittedly, the 95 percent confidence interval spans zero). 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 BDT 35 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

[32] This result arises due to the lack of correlation between the WTP for the individual components, a result which itself arises due to the lack of correlation between the random taste coefficients.

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. Based on the positive marginal utility of short duration, 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. As noted, however, with a 95 percent confidence interval spanning zero, we have limited confidence in overall sign associated with the estimated WTP. 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 under BDT 260 for a limited-coverage policy and just under BDT 320 for a full-coverage policy. These valuations are well above actuarially fair prices for these instruments (roughly BDT 48 and BDT 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 three times the actuarially fair cost of this insurance. For the limited-coverage insurance product, however, the net benefit perceived is more than five times as large as the cost of actuarially fair insurance. From a purely economic standpoint, this sort of basic benefit/cost ratio suggests that, even without being bundled with the DT 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 payouts 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 5 compares the actual probability of different events occurring, as well as the derived subjective probabilities based on WTP estimates derived from column (III) of Table 3 (not reported here).[33] These results clearly demonstrate that farmers overestimate the probability of different-length dry spells occurring, and by a large margin. Interestingly, we estimate incredibly similar subjective probabilities for 14-day dry spells based on farmers' WTP for different index insurance products. Based on the unconditional WTP estimates, we estimate that, on average, farmers would be willing to pay BDT 220 for a full coverage, high trigger policy that pays BDT 600 for after a 14-

[33] 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.

day dry spell. For a limited coverage, low trigger policy, which pays BDT 300 after a 14-day dry spell, we estimate that farmers would, on average, be willing to pay nearly BDT 110. While these WTP estimates are quite different, they suggest almost identical subjective probabilities that the insurance will be triggered (roughly 37 percent subjective probability). Furthermore, we note that the overestimation is increasing in the length of the dry spell. In other words, farmers overestimate the probability of an 18-day dry spell (subjectively estimated as nearly 8 times more likely than objectively probable based on historical data) more than they overestimate the probability of a 14-day dry spell (subjectively estimated at roughly 3.75 times more likely than the historical data would suggest), which they in turn overestimate more than the probability of a 12-day dry spell (subjectively estimated at only 1.7 times more likely than historical data would suggest). 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 25 percent. To frame this in terms of return periods, farmers anticipate an 18-day dry spell roughly once every 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 not be consistent with full rationality, it is also not entirely 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).

[Table 5 Approximately Here]

Returning to Table 4, 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 4 reports the marginal WTP for the DT rice component in the unbundled case and assumes that there is no insurance, so 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.

As previously discussed, the WTP for unbundled DT rice is negative, 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. As mentioned earlier, 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 and vice versa. This is evident from the increasing (and now, on average, positive) WTP for the DT-seed component of a DT-WII bundle reported in row (2) of Table 4. On average, farmers would be willing to pay roughly BDT 260 for an unbundled limited-coverage insurance product; if it were bundled with DT rice, however, farmers would be willing to pay nearly BDT 330 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 roughly as much as the independent full-coverage WII product, even though the full-coverage WII policy pays out 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 approximately BDT 360 for a bundle including a short-duration DT rice (similar to BRRI dhan 56) and a limited coverage WII policy. 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; because of the manner in which our choice tasks 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.

In Figure 4, we present the individual-level (conditional) estimates of WTP for these various drought risk management products, based on the conditional marginal utility distributions. In this figures, the black dots represent each individual's expected WTP, while the grey bands represent each individual's 95 percent confidence interval for WTP. Across all the panels, those corresponding to the insurance products show a much greater degree of clustering in individual's WTP. There is much greater dispersion in individuals' WTP for short duration DT, which in turn is largely due to heterogeneity in individuals' WTP for the DT yield distribution. The uncertainty inherent in our estimates of individual's WTP for these different drought risk management products vividly illustrates the propagation of uncertainty that arises from analyzing functions of random variables. Even for the most clustered scattering of expected WTP across individuals in the sample, uncertainty increases to such a degree that most individual's confidence intervals span zero. Under these conditions, the expected WTP that is estimated for each individual may provide the most information that we can reasonably make use of.

[Figure 4 Approximately Here]

In Figure 5, we present a series of demand curves based on estimates of WTP derived from conditional marginal utility estimates.[34] We present three demand curves in this figure, one corresponding to the DT variety (independent of insurance), one for a limited coverage WII product, and one corresponding to the bundle of DT with a complementary WII policy. The results largely suggest that WTP for the bundled DT-WII product exceeds WTP for other

[34] One important caveat must be noted regarding the results implied by this demand curve. The conditional marginal utility and WTP estimates on which these curves are based are specific to the farmers included in the sample, and may not be useful for making out-of-sample predictions. This may be especially true in this application, since many of the sample farmers are members of GUK, and may therefore be systematically different from other farmers in Bogra district, let alone other farmers throughout Bangladesh.

drought risk management alternatives for almost all members of our sample. Furthermore, almost all farmers in our sample have an expected WTP for the DT-WII bundle that exceeds the sum of the cost of the two products (i.e., the actuarially fair cost of the insurance and the cost of the seed). This suggests that farmers would typically derive a great deal of surplus from purchasing the bundled product at a price close to actuarially fair. Furthermore, there may also be scope for the insurance component of this bundle to be priced above the actuarially fair cost, including such additional components as risk premium and administrative loads. Insurers' ability to incorporate these other costs increases the viability of such an insurance regime.

[Figure 5 Approximately Here]

8. Conclusions and Policy Implications

In this study we have made several contributions to the literature on agricultural risk management in developing countries. First, building on the work of Lybbert and Carter (2015), we have explicitly illustrated how insights from Extreme Value Theory could be used to calibrate a WII product to complement the performance profile of a DT rice variety. Subsequently, 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. We have shown that bundling DT rice with a properly calibrated WII product reduces the cost of the insurance component of the bundle, and these reductions in the cost of insurance are substantial: for the bundled product specified in this paper, we estimate a reduction of 58 percent.

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 slight yield penalty under normal or irrigated conditions relative to varieties commonly grown during the monsoon season in Bangladesh. 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 observe these relative benefits and would therefore likely 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 at significantly more than their actuarially fair values, though admittedly our discrete choice experiment does not allow us to quantify or monetize the disutility associated with basis risk. 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 (Miranda and Farrin 2012). 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. 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.

On the whole, our results suggest that bundling DT rice with WII may provide a mechanism for managing drought risk, and may result in increased demand for both DT and WII while simultaneously reducing the cost of the complementary insurance component. While we cannot say for certain that either DT or WII will necessarily be welfare-enhancing, there is the possibility that the bundled product may be; an assertion strengthened by the WTP estimates reported here. Some emerging evidence suggests that the impacts of both DT and WII have been positive. Karlan et al. (2014) and Hill et al. (2017), for example, have recently demonstrated how weather index insurance led to increased investments in inputs such as fertilizers and irrigation, while Cole, Giné, and Vickery (2013) and Mobarak and Rosenzweig (2016) have demonstrated how WII has led farmers to shift agricultural practices to higher value crops. Emerick et al. (2016) have recently demonstrated how a submergence-tolerant rice variety in eastern India led to an increase in investments in modern agricultural inputs and an increase in productivity. While they argue that technological innovations such as stress-tolerant seeds may provide a meaningful solution to the problem of uninsured risk in developing country agriculture, given the nonmonotonic yield benefits of these stress-tolerant varieties, a bundled product that provides more comprehensive risk management may yield even greater benefits.

While the results of our discrete choice experiment suggest a possible role for this bundled risk management product, it remains to be seen whether this package could actually be a marketable product in practice. While the DT acts as a quasi-insurance instrument, various sources of agronomic and environmental heterogeneity make it difficult for farmers to fully understand the costs and benefits of the technology, and even in conjunction with WII, which suffers from basis risk, farmers may simply perceive that the complementary product is simply insufficient to overcome these weaknesses. Even if a market for this product were to emerge, it is unclear whether it would result in appreciably different short- and long-run behavior vis-à-vis either traditional, multiple peril crop insurance or other forms of informal risk management.

There is also an unanswered question as to the role of government incentives – specifically subsidies – that may be required to stimulate sufficient demand for these products to be viable. This is perhaps the central question that this research aims to inform. While some argue that subsidies may be required to encourage uptake in the short run (e.g., J-PAL, CEGA, and ATAI 2016), large subsidies distort prices and are almost always unsustainable. There are other potential roles for government interventions that could also increase uptake in a more sustainable fashion. For example, governments could invest in seed research and development to generate drought tolerant cultivars with even greater drought tolerance or even drought resistance traits. As we have demonstrated here, bundling WII with a stress-tolerant variety lowers the insured amount and lowers the cost of the insurance component for the consumer. Alternatively, government investments in weather stations or remote sensing technologies could result in reduced basis risk, which in turn could make WII products more attractive without necessarily aggravating moral hazard. There is also the need for continued research into methodologies for refining the construction and measurement of insurance indexes. The particular index used in this experiment is imperfect, since the effect of dry spells on yields depends crucially on the timing of the dry spell in the crop growth cycle. While we are not in a position to recommend any specific design enhancements based on the results of the present study, continued research in this area to improve index design and measurement is surely warranted. The exploration of these potentialities could be a fruitful area of research, and could prove valuable for policymakers as they consider these types of agricultural risk management strategies.

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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

Attribute	Level	Label	Days
Duration (days from nursery to harvest)	**1**	Short	< 120
	2	Medium	120–135
	3	Long	> 135

Attribute	Level		Trigger (consecutive dry days)	Insurance payment (BDT)
Weather index insurance	**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

Attribute	Level	Bundle price (BDT)
Bundle price	**1**	20
	2	60
	3	80
	4	120
	5	150

Source: Authors.

Table 2. Summary statistics of sample households

Variable	Mean	SD
Household head is male (=1)	0.9312	0.2532
Household head age	42.9385	11.7095
Rice yield (kg/decimal)	16.7727	7.5495
Irrigation used on rice (=1)	0.6676	0.4711
Pesticide, insecticide or herbicide used on rice	0.7977	0.4018
Proportion of farmers with a savings bank account	0.2892	0.4535
Proportion of farmers who are members of informal savings groups	0.2004	0.4004
Proportion of farmers who have a savings box at home	0.3100	0.4626
Amount saved in a good month (BDT)	1,462.3980	5,101.7110
Proportion of households where an adult member has taken a loan in the last 12 months	0.9363	0.2442
Bought weather/crop insurance (provided by the government or a private company)	0.1233	0.3289
Know anyone who bought weather/crop insurance (provided by the government or a private company)	0.1474	0.3546

HH Head literacy	Percent	Cumulative
Cannot read and write	15.63	15.63
Can sign only	34.89	50.52
Can read only	0.17	50.69
Can read and write	49.31	100

Which of the following statements best describes your current cash savings?	Percent	Cumulative
More than enough	45.63	45.63
Enough for regular consumption needs and small unexpected expenditures	22.29	67.92
Just enough for regular consumption needs	12.55	80.48
Not enough for consumption needs	19.52	100
Number of Observations		**2,314**

Table 3. Random parameters logit results

	(I)			(II)			(III)		
	Coefficient		Std. Error	Coefficient		Std. Error	Coefficient		Std. Error
Random coefficients									
Drought tolerance (DT)	-1.320	***	0.057	-1.331	***	0.057	-1.733	***	0.156
Short duration	1.431	***	0.066	1.445	***	0.067	1.433	***	0.068
Medium duration	0.530	***	0.050	0.538	***	0.051	0.526	***	0.054
Limited coverage/low trigger	1.040	***	0.078	1.042	***	0.078	0.964	***	0.100
Limited coverage/high trigger	1.332	***	0.104	1.338	***	0.105	1.311	***	0.154
Full coverage/low trigger	1.103	***	0.090	1.108	***	0.090	0.855	***	0.115
Full coverage/high trigger	1.938	***	0.083	1.954	***	0.082	1.959	***	0.101
Price (Negative, 100 Taka)				0.824	***	0.064	0.884	***	0.071
DT x Limited coverage/low trigger							0.326	**	0.162
DT x Limited coverage/high trigger							0.292		0.206
DT x Full coverage/low trigger							0.681	***	0.183
DT x Full coverage/high trigger							0.286	*	0.156
Non-random coefficients									
Price (Negative, 100 Taka)	0.781	***	0.058						
ASC - Status Quo	-5.707	***	0.250	-5.738	***	0.247	-5.601	***	0.256
Distributions/limits of random coefficients									
SD (Drought tolerance (DT))	1.475	***	0.077	1.481	***	0.078	1.477	***	0.078
SD (Short duration)	0.974	***	0.097	0.977	***	0.097	0.988	***	0.105
SD (Medium duration)	0.056		0.068	0.119		0.114	0.128		0.132
SD (Limited coverage/low trigger)	0.019		0.037	0.046		0.049	0.013		0.049
SD (Limited coverage/high trigger)	0.832	***	0.218	0.864	***	0.215	0.942	***	0.208
SD (Full coverage/low trigger)	0.347	**	0.176	0.367	**	0.172	0.056		0.212
SD (Full coverage/high trigger)	0.517	***	0.144	0.507	***	0.147	0.536	***	0.171
Limits (Price)				0.824	***	0.064	0.884	***	0.071
SD (DT x Limited coverage/low trigger)							0.248	*	0.148
SD (DT x Limited coverage/high trigger)							0.295		0.355
SD (DT x Full coverage/low trigger)							0.480		0.299
SD (DT x Full coverage/high trigger)							0.543	*	0.316
Number of households (n)	2,314			2,314			2,314		
Number of choice sets per household (J)	5			5			5		
Total number of observations (N)	11,570			11,570			11,570		
Parameters estimated (K)	16			17			25		
Log-likelihood	-6,546.59			-6,541.90			-6,533.00		
Pseudo R^2	0.485			0.485			0.486		
Akaike Information Criterion (AIC)	13,125.19			13,117.80			13,116.00		
Bayesian Information Criterion (BIC)	-6,471.74			-6,462.37			-6,416.05		

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. All models assume non-price coefficients follow a truncated normal distribution. Model (I) assumes a homogeneous price coefficient, while models (II) and (III) assume that price follows a one-sided triangular distribution.

Table 4. Empirical estimates of population mean 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]	-34.00	[-97.52, 29.52]
(2)	WTP for short duration DT rice seed[b]	35.95	[-28.87, 100.78]
(3)	WTP for full coverage weather index insurance (WII) policy[a]	318.11	[269.26, 366.95]
(4)	WTP for limited coverage WII policy[a]	257.19	[215.52, 298.85]
(5)	WTP for limited coverage WII policy[c]	327.14	[283.52, 370.76]
(6)	WTP for short duration DT + limited coverage WII policy	363.09	[284.96, 441.23]

Note: [a] Unbundled, main-effect only; [b] Bundled with limited-coverage weather index insurance product; [c] Bundled with drought-tolerant rice. Means approximated by summing population expected WTP for various individual components based upon posterior mean coefficient estimates reported in Table 2. Confidence intervals derived based upon approximated variance of WTP, which is the sum of variances in WTP for various individual components (assuming no covariance due to uncorrelated underlying random 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 5. Farmers' subjective assessments of probabilities of different-length dry spells

Length of dry spell	Actual probability	Mean subjective probability
12 days	0.187	0.322
14 days	0.098	0.369†
14 days	0.098	0.363††
18 days	0.031	0.247

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

Figures:

Figure 1. Sample choice task

Figure 2. Bogra district, Rajshahi division, Bangladesh

Figure 3. Densities of random coefficients based on posterior moments

Note: Densities based on simulated populations of 100,000 hypothetical subjects with preferences drawn from posterior (unconditional) moments. Shaded areas represent 95 percent confidence intervals.

Figure 4. Individual-level (conditional) estimates of WTP for various drought risk management products

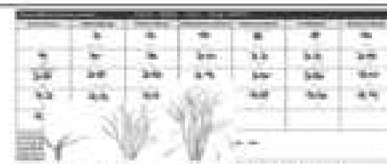
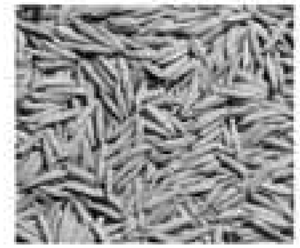
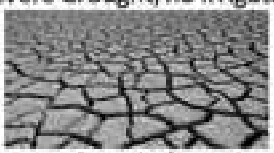
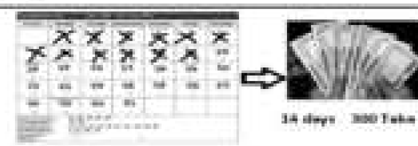
Notes: Black dots represent each individual's expected WTP for different risk management products derived from conditional marginal utility estimates. Grey bands represent each individual's 95 percent confidence interval.

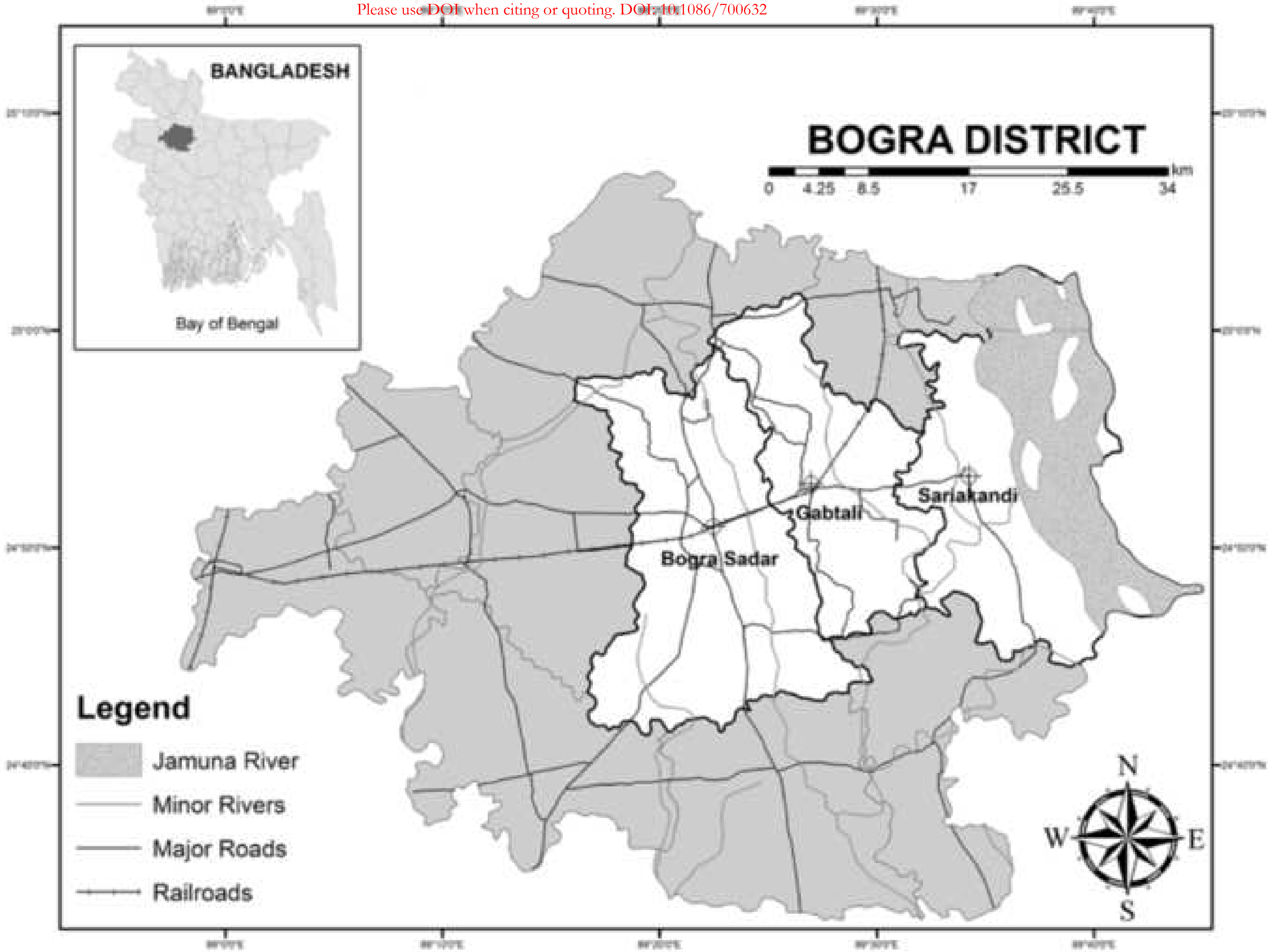
Figure 5. Estimated demand curves for drought risk management products

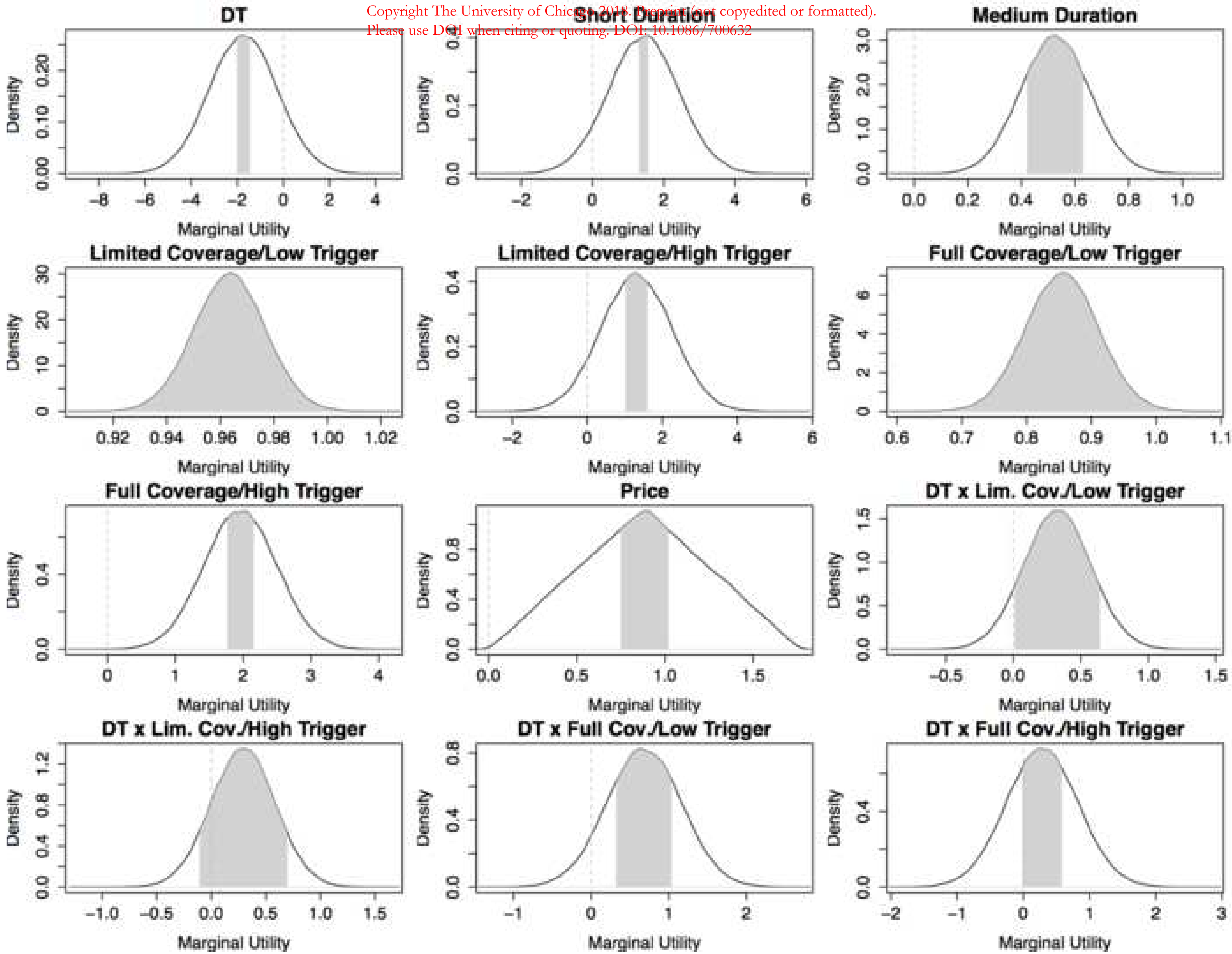
Note: Demand curves based on individual-level expected WTP.

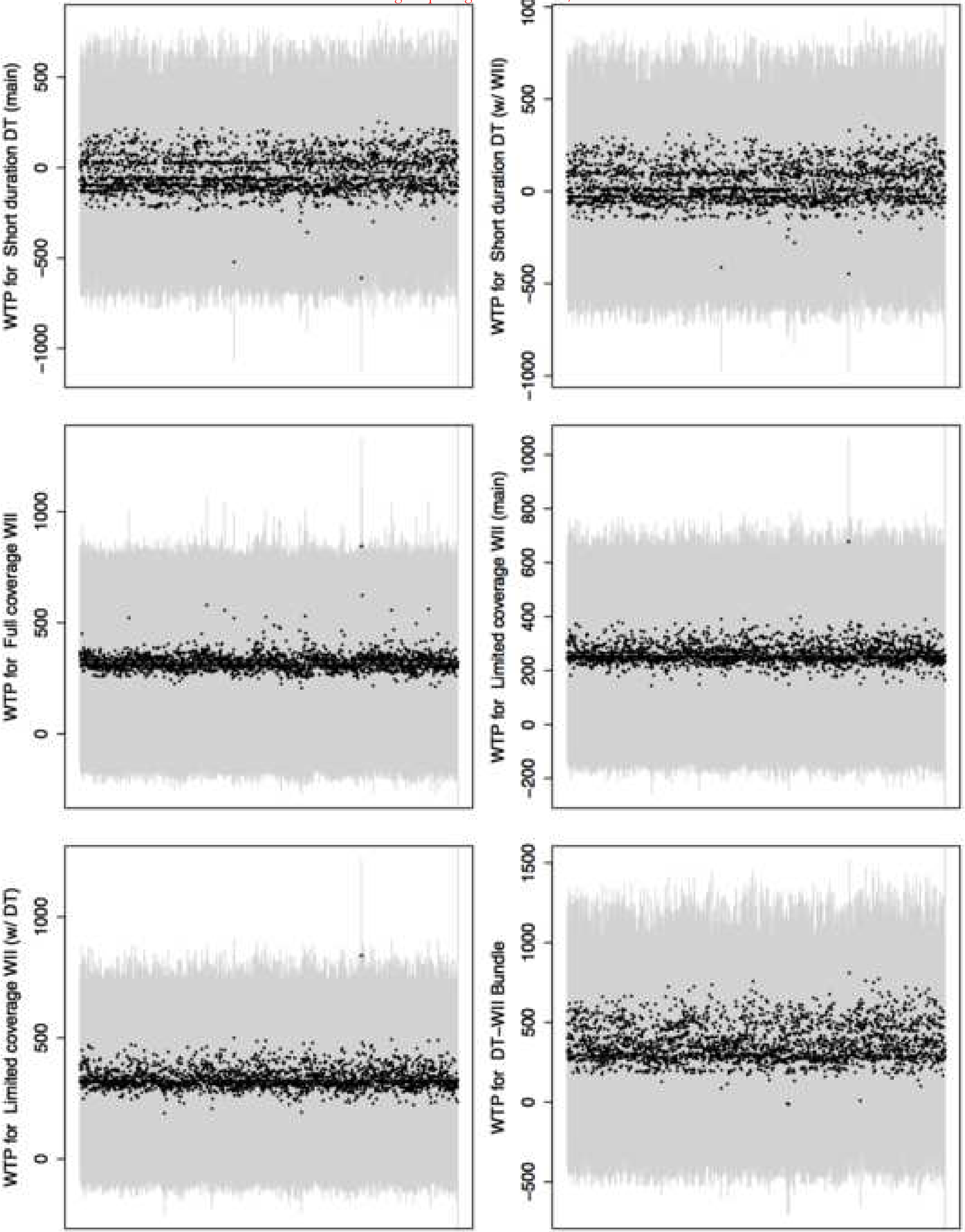
CHOICE SET 3 OF 5

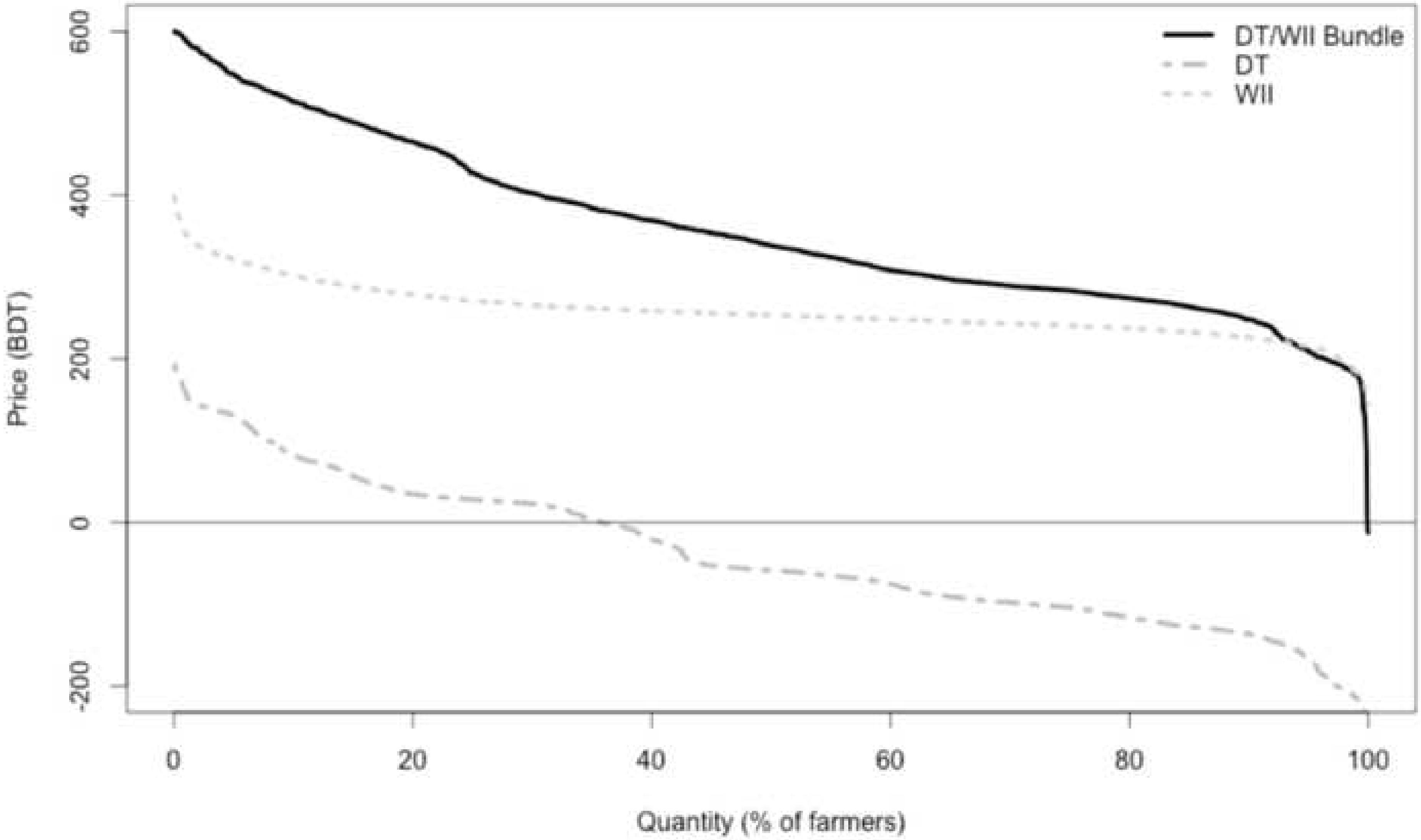
ASSUME THAT THE FOLLOWING THREE SEED AND INSURANCE OPTIONS WERE THE ONLY CHOICE YOU HAVE, WHICH OPTION WOULD YOU CHOOSE ?

SEED/INSURANCE CHARACTERISTICS	OPTION A	OPTION B	OPTION C
DURATION (DAYS)	 Long (Greater than 135 days)	 Short (Less than 120 days)	I PREFER THE BUNDLE OF SEED AND INSURANCE (IF ANY) THAT I HAD USED IN THE LAST AMAN SEASON. 
YIELD(MAUNDS/BIGHA)			
 Normal conditions/Irrigated	23 (Maunds/Bigha)	19 (Maunds/Bigha)	
 Moderate drought/no irrigation	9 (Maunds/Bigha)	12 (Maunds/Bigha)	
 Severe drought/no irrigation	4 (Maunds/Bigha)	6 (Maunds/Bigha)	
 Extreme drought/no irrigation	1 (Maunds/Bigha)	1 (Maunds/Bigha)	
INSURANCE	 14 Days : BDT 600	 14 Days : BDT 300	
TOTAL SEED/INSURANCE PRICE	 BDT 150	 BDT 120	


BANGLADESH
Bay of Bengal
BOGRA DISTRICT
km
0
4.25
8.5
17
25.5
34
Sariakandi
Gabtali
Bogra Sadar
Legend
Jamuna River
Minor Rivers
Major Roads
Railroads
N
W
E
S


DT
Short Duration
Medium Duration
Limited Coverage/Low Trigger
Limited Coverage/High Trigger
Full Coverage/Low Trigger
Full Coverage/High Trigger
Price
DT x Lim. Cov./Low Trigger
DT x Lim. Cov./High Trigger
DT x Full Cov./Low Trigger
DT x Full Cov./High Trigger
Density
Marginal Utility


WTP for Short duration DT (main)
WTP for Short duration DT (w/ WII)
WTP for Full coverage WII
WTP for Limited coverage WII (main)
WTP for Limited coverage WII (w/ DT)
WTP for DT–WII Bundle


DT/WII Bundle
DT
WII
Price (BDT)
600
400
200
0
-200
0
20
40
60
80
100
Quantity (% of farmers)