Achieving Development Impact with Complementary Stress-resistant Seed & Financial Technologies: A Proposal to Learn from the DTMass Scaling in Mozambique & Tanzania

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1. Can Stress-resistant Agricultural Technologies Boost Human Nutrition and Development?

The study proposed here takes a novel approach to answering the question of how agricultural interventions can be designed to improve nutritional outcomes for individuals in farm families and communities as a whole. Most often, this question is approached by considering interventions or technologies that will, in a typical crop year—or on average—increase the local availability of nutritionally dense foods, or increase the incomes of rural families. Here we instead consider the nutritional impact of scaling up “stress-resistant” agricultural technologies that are designed to stabilize production and incomes in atypical or bad crop years.

First and foremost, this approach should reduce the human development losses that occur during periods of drought and other types of climatic stress that reduce incomes for both farm and landless labor families. Second, stress-resistant technologies pay a further “risk-reduction dividend,” inducing behavioral change on the part of producers who intensify production, raising incomes and food availability levels in average, non-stress years. While stress-resistant technologies have been recently developed and proven, there is scant evidence to date that their promotion can fundamentally improve nutritional outcomes. As we know that agricultural income increases are often only weakly wed to improved nutrition outcomes (Behrman, 1988), it is the goal of this study to fill this knowledge gap and determine if stress-resistant technologies are a cost-effective approach to meeting nutrition and health goals.

Specifically we propose to implement a multi-year, spatially diversified randomized controlled trial of two proven, complementary, stress-resistant technologies: drought tolerant maize seeds and index insurance fine-tuned to cover the high stress conditions when drought-tolerant maize fails. In addition, we will also explore whether the impacts of the stress-resistant technologies are shaped by women’s economic intra-household bargaining power.

Before turning to the details of our proposed study, the remainder of this section provides additional background on climatic stress and nutrition and on how stress-resistant agricultural technologies function.

1.1. Human Development Consequences of Climatic Stress

The human development consequences of climatic stress is powerfully illustrated by the work of Hoddinott and Kinsey (2001), who use data from southern Africa to show that on average in times of drought, maternal BMI declines, growth of older children slows (later to recover), while younger children become permanently stunted, with no compensatory growth in post-drought years. A recent study of drought in Brazil (Rocha and Soares, 2015) shows significant impacts on birthweight and morbidity. Reflecting perhaps the combined effects of all these forces, Ampaabeng and Tan (2013) use data from Ghana and show that early childhood experience of a drought event severely damages the long-term cognitive development. It is precisely these long-term, irreversible consequences of short-term nutritional shocks that prioritize the promotion of stress-resistant agricultural technologies.

However, as is often the case, average impacts can obscure as much as they illuminate. Hoddinott and Kinsey and later Hoddinott (2006) go on to show that the average impacts of drought on stunting that they identify are primarily driven by impacts in the poorest households. The impact of drought on children in these households is 50% more severe than the estimated average effect, and there is no statistically significant impact of drought on child growth in the less poor households in their study.

This differential exposure of poorer households to climatic stress is a more general and somewhat subtle phenomenon. In the first instance, it may seem obvious that consumption must collapse when crop and labor incomes fail in the face of drought. Lacking financial instruments and the ability to borrow against income in better, future years, it would seem that consumption must fall as income falls. In fact, of course, households are well aware of the prospects of drought years and can accumulate buffer assets in good years that can be sold in times of stress. In the arcane language of economics, households' ability to "smooth consumption" through sale and purchase of assets should delink nutrition from climatic stress.

There is, however, an important caveat to this story. Figure 1, taken from Carter and Lybbert (2012), shows how rural households in rural Burkina Faso cope with drought stress. In principal, these households can offset income losses and smooth consumption by either selling accumulated stocks of animals or by drawing down on grain stores. The solid, downward-sloping line labeled "complete smoothing locus" shows the different combinations of livestock sales and grain stock depletion that would allow households to completely smooth consumption and insulate nutrition from climatic shock. For instance, a household could protect consumption and nutrition from drought by selling only livestock, by drawing down only on grain stores, or by some combination of both asset depletion strategies.

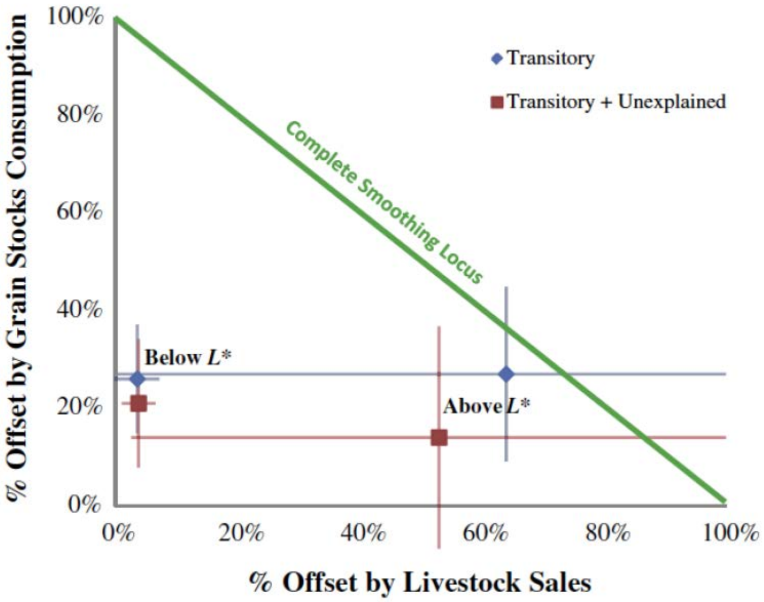

Figure 1 Differential Ability to Cope with Draught

The interesting and important question is what do households actually do. As econometrically analyzed by Carter and Lybbert, the Burkina data reveal that better-off households almost completely insulate consumption from the drought shock by selling off or drawing down assets that are equal in value to almost 90% of the drought-induced income losses. Their estimated strategy is shown by the diamond shape marker above "above *L**," meaning they have more than a critical amount of initial wealth. That is, these households smooth away 90% of the climatic shock.

In contrast, poorer households with less than *L** units of initial wealth smooth away only 30% of the shock, indicating that 70% of the shock is absorbed as decreased consumption, with predictable nutritional consequences. While it may seem that this highly imperfect consumption smoothing by poorer simply reflects a lack of assets, such is not the case in the Burkina data. Nearly all the poorer households had additional livestock assets, which they chose to protect rather than sell as a drought-coping mechanism. More generally, asset protection strategies—not consumption smoothing—by poor households is entirely understandable from a forward-looking perspective. Liquidating too many assets today only heightens future vulnerability, giving households the unfortunate choice of not eating today or likely being even worse off in the future (see Zimmerman and Carter 2002 for a theoretical deep dive into this issue).

The key point here is that climatic stress will differentially reduce consumption and nutrition by the poorest households who either do not have assets or will struggle to protect their modest remaining assets. And yet, as Hoddinott (2006) quips, this asset protection strategy might be more accurately described as inter-generational asset shifting, as the current consumption and nutrition shortfalls draw down on the future human capital of the youngest household members. It is this linkage to the future that makes so important the pursuit of stress-resistant strategies that insulate household income from climatic shocks.

1.2. How Stress-resistant Agricultural Technologies Work

Given that climate-induced fluctuations in income are an important part of the undernutrition story and the inter-generational transmission of poverty, the question becomes, then, what to do about it. In thinking about this question, it is important to recall that rural wages are also damaged by climate shocks such as drought which shrink labor demand (*e.g.*, see the work by Jayachandran, 2006). The landless and land poor also have a stake in stress-resistant technologies that operate by bolstering agricultural production and incomes.

Recent years have seen the separate development of two technologies designed to help small-scale farmers manage climatic stress. The first technology is seed varieties that better withstand abiotic stresses like droughts and floods. The second is the financial technology of index insurance that transfers risk out of small-scale farming systems by issuing compensatory payments when climatic events occur and agricultural production collapses. Insurance can also in principal cover biotic stresses such as massive pest invasions. Up to a point, these two technologies work in the same way. However, they also have some important differences and can complement each other. Exploiting these complementarities is an important part of the learning agenda proposed here.

Turning first to the similarities, both stress-resistant seeds and insurance are designed to stabilize producer incomes in the wake of an adverse event. For example, a recent RCT studies the impact of a new flood tolerant rice variety in parts of India. While this study did not study nutritional impacts, it did show that yields were 25% higher on flood-stricken fields with the new seeds than without (Emerick *et al.*, 2014). In a similar spirit, Janzen and Carter (2014) use an RCT to study the impacts of index insurance payouts issued in the wake of a severe drought in Northern Kenya. Not only were the payments made quickly and automatically, they cut in half the reliance by poorer households on reduced food consumption as a coping strategy (wealthier households were already consumption smoothing before the payouts, and the payouts allowed them to sell off fewer assets while maintaining consumption levels).

In addition to their common ability to stabilize producer incomes in the face of shocks, both seed and financial technologies exhibit what might be called a risk reduction dividend. The RCT of flood tolerant rice showed that farmers with the stress-tolerant seed responded at the beginning of the crop year (pre-stress) by investing more heavily in all their rice fields (also see Dar *et al.*, 2013). That is, a risk reduction technology by itself induces significant *ex ante* behavioral change, empowering producers to undertake profitable investments that they otherwise would avoid for fear of risk. Risk reduction, in other words, pays a dividend in the form of increased investment and expected income in average years.

Recent index insurance RCT's also detect a similar risk reduction dividend. The Karlan *et al*. (2013) study of Ghanaian maize farmers and the Elabed and Carter (2014) study of Malian cotton farmers both find that index insurance boosts agricultural intensification and expected farm incomes by something in the range of 25 to 35 percent. While none of these studies have yet examined the nutritional impacts of this risk reduction dividend effect, the effect is part of what may make stress-resistant technological change a cost-effective way to reach nutritional goals.

While seed and financial technologies operate in many of the same ways—and thus might be seen to be substitutes for each other—they are two important differences between them. First, because stress-resistant seeds bring some local production (and labor demand) under conditions of climatic stress, they should in principal stabilize wages in bad years, thereby assisting landless and labor supplying rural households. In contrast, insurance payments inject liquidity, but not directly labor demand, during a drought (or flood) year. One solution, suggested by Mobarak and Rosenzweig (2012) is to sell index insurance policies to landless laborers also.

A second, and perhaps more important difference between stress-resistant seed and financial technologies, is that the former fails under extremely adverse events, whereas the latter does not. For example, the flood resistant rice varieties can survive up to 17 days of submergence because of flooding. Beyond 17 days, these varieties die and yield nothing, just like conventional rice varieties. A similar limitation applies to drought tolerant maize varieties, a point to which we return in detail in the next section. In contrast, insurance contracts can continue to pay (and pay more), the more severe stress conditions become. In other words, there is a natural complementarity between the seed and financial technologies, an issue again to which we return soon.

1.3. The Learning Opportunity

While the work to date on these new technologies is encouraging, it has neither explored their complementarities, nor has it traced out their impacts on nutrition. With new drought tolerant (DT) maize varieties ready to go to market, and with our growing knowledge of how to design effective insurance products for small-scale agriculture (de Janvry *et al.*, 2014), now is an opportune moment to close this critical knowledge gap.

Charged with reducing vulnerability and improving food security, the Drought Tolerant Maize for Africa (DTMA) project has developed over 140 DT maize varieties. These breeding efforts have generated a pipeline of new DT maize products that have been tested in field trials and on-farm trials and that are beginning to reach farmers through National Agricultural Research Systems and private seed company partners. DT field trial data reveal impressive results overall.

However, under extreme drought conditions (which may occur as much as 20% of the time in some African maize-growing regions), new DT varieties, like conventional varieties, fail. It is under these conditions that novel financial technologies, like index insurance, can potentially complement and deepen the impact of DT seed technologies on the livelihood prospects and vulnerability of poor farmers (see Lybbert and Carter 2014).

The proposed study will determine the uptake and impacts on nutritional outcomes of DT varieties alone and in combination with complementary financial technologies. We will also test whether women experience stronger intra-household bargaining positions.

2. Completed Feasibility Research

Our proposed study relies on two component pieces: Drought tolerant maize seed technologies (DT); and, Agricultural Index Insurance (II). Additional details are available from the authors on this intervention and its logic.

This section first reviews what we have already learned about the efficacy of DT and II technologies in isolation. The section closes with an *ex ante* analysis of the complementarities between DT and II technologies.

2.1. Efficacy and Limitation of DT Maize Seed Technologies

The DTMA project has obtained some remarkable achievements thus far. Under limited release, DT varieties have gained substantial farmer acceptance. CIMMYT reports uptake rates of 17% in Ethiopia, 32% in Uganda, 18% in Tanzania and 7% in Kenya.

While these adoption-monitoring figures are encouraging, to understand their potential nutritional impacts, it is important to understand fully how DT varieties work and what their strengths and weaknesses are. Using data from DTMA field trials in 2011, we compare the yield performance of the three top performing new DT maize varieties with the three best widely-available commercial varieties. These field trials were conducted across 49 sites in Eastern and Southern Africa. Within each site we average the yield of the three top non-DT commercial varieties and use this as an implicit measure of growing conditions (especially rainfall and therefore drought pressure), which vary from site to site in 2011. We plot cumulative yield distributions of the top DT varieties and of this average yield for top commercial varieties in Figure 1.

In this figure, the horizontal axis is yield and the vertical axis is the share of sites with yield at or below the yield level on the horizontal axis. Improved yield performance can therefore be seen as a rightward shift in a given distribution. The superior yield performance of DTMA's new DT varieties is clear over much of the range of growing conditions captured by rainfed yield outcomes.

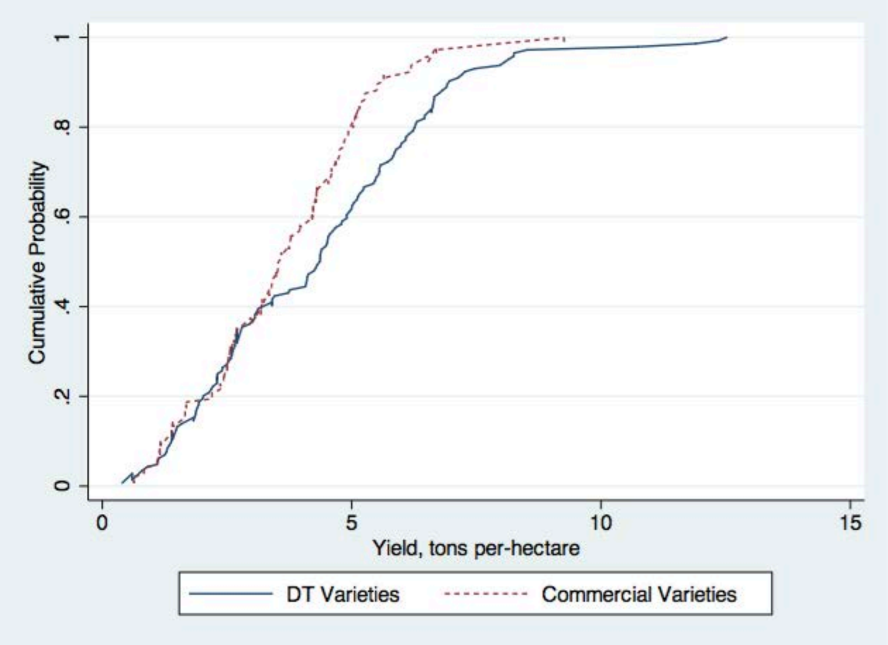

Figure 2 On-farm Trials of DT versus Non-DT Varieties

To understand how performance varies across this range, suppose that the 90th percentile in the yield distribution of commercial varieties reflects good rainfall, that the 50th percentile reflects moderate drought pressure (i.e., moderate drought is the median growing condition) and that the 30th percentile reflects severe drought conditions. The DT yield advantage is 15-20% over good rainfall and moderate drought pressure, but falls to zero under severe drought pressure. That is, beyond a certain point of drought stress (yield of about 3 tons/ha in this case), the DT varieties confer no yield protection relative to existing commercial maize varieties. We refer to this as the 'red zone.'

Figure 1 shows that DT varieties are drought tolerant, but not drought proof. Is this limitation severe enough to prevent DT from attaining its desired impact? In locations where 'red zone' drought events occur with some frequency, this is indeed a serious limitation that deserves careful attention. As described elsewhere (Lybbert and Bell, 2009), this 'red zone' effect implies that DT varieties may fail to perform precisely when smallholder farmers need drought protection the most. This observation in turn suggests that incentives for DT adoption will be weakened in areas with high red zone probabilities, reducing the *ex ante* impacts of DT technologies. It also suggests that for a significant portion of severe drought events, there will be no *ex post* impacts of DT varieties as farmers using those varieties will be no better off than those using non-DT varieties under these red zone circumstances.

We turn now to see how to leverage the impressive yield performance of DT varieties under good conditions and moderate drought and simultaneously provide drought protection for more severe 'red zone' events using complementary financial innovations.

2.2. Design & Efficacy of Agricultural Index Insurance

Agricultural index insurance works not by insuring the farm household directly against its own specific income or yield losses, but instead by insuring against a direct measure or prediction of the average or typical losses experienced by farms located in the vicinity of the household. This characteristic is both a strength and a weakness of index insurance. It is a strength because the index obviates the need to measure losses separately for each farm (having to do so for small farms is cost-prohibitive). Further, reliance on an index that cannot be influenced by the actions or characteristics of the insured minimizes problems of moral hazard and adverse selection that could otherwise cripple efforts to offer insurance to small-scale farmers.

However, reliance on an index that is correlated with, but not identical to, farm-specific outcomes is also a weakness of index insurance. If that correlation is weak, then index insurance may fail to protect farmers when climatic shocks hurt them the most, destroying the utility of insurance as a stress-resistant agricultural technology.

Not unlike seed technologies, creation of effective index insurance technologies has faced its own "breeding" challenges to find indices that provide adequate insurance protection. While there is emerging evidence (summarized in the prior section) that index insurance can work and pay the risk reduction dividend, there are also examples of index insurance failures, typically based on simple rainfall-based indices, that do not correlate well with farmer losses (Clarke 2013).

Learning from this experience, we propose here to design an index insurance contract that is based on three lessons that have emerged from the now rich experience testing and piloting index insurance products:

1. The primary index must be subjecting to ground-truthing and designed to correlate well with actual farmer losses. Recent advances in the use of satellite measures (such as high resolution measures of evapotranspiration and gross primary production) show these to be the best indices to use in areas where there is not reliable yield data that can be used for an area yield index.

2. Even a high quality index based on high-resolution remote sensing data will fail to properly measure farmer losses in maybe 1 of 5 climatic stress events. Well-designed index insurance should thus be combined with a 'fail safe' audit rule in which communities can demand a secondary, on the ground

crop loss measurement. Hill *et al.* (2014) describe the successful use of this hybrid approach to index insurance in Ethiopia.

3. Insurance is most effectively explained and sold when it is bundled with a new technology (such as a seed variety), as shown by the successful experience of the Syngenta Foundation's Kilimo Salama program in Kenya and elsewhere in East Africa.

Building on these principals, this project will rely on the substantial experience of the UC-Davis I4 Index Insurance Innovation Initiative and work with private sector partners to design an index insurance contract fine-tuned for DT maize and consistent with these principles (the I4 has been at the forefront of efforts to use satellite data and hybrid contracts, which mix index contracts with fail-safe on the ground audit rules, to create index insurance technologies that offer reliable protection to farmers). The research team already has a rich program of work on predicting crop yields for insurance purposes in Tanzania. The team is also connected to groups currently implementing index-based crop insurance programs in Mozambique.

2.3. Bundling Drought Tolerant Maize and Index Insurance[1]

The complementarity between index insurance and DT varieties stems from the fact that index insurance can insure extreme 'red zone' drought events where DT varieties offer little or no protection. Of course, index insurance (II) can also be designed to protect against moderate drought as well, but DT varieties are almost certainly more cost-effective than index insurance for such moderate drought events. Properly bundled, they offer a relatively low cost, but complete and effective risk management tool.

With the specific limitations of stand-alone DT and II in mind, we now turn to the complementarity that makes bundling them potentially interesting. This complementarity, which is tied to drought severity, is quite simple. A bundled DT-II product can offer monotonic benefits as drought severity increases because II can incrementally cover the severe drought pressure beyond the point where relative DT benefits begin to fade. On the flip side, with DT covering low to moderate drought events, II can be designed so it only covers rarer and more extreme droughts, which can substantially reduce the actuarially fair premium associated with the insurance.

While compelling in the abstract, how well might this bundle work in practice? To gain purchase on this problem, Lybbert and Carter (2014) use maize data from a drought-prone region of Ecuador to analyze how a DT-II bundle would operate in practice. Ecuador is convenient for this analysis as the government has long

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[1] This section borrows liberally from Lybbert and Carter (2014).

collected reliable yield data that can be used to estimate underlying probability structures and simulate how different risk-reducing technologies would work. In Figure 3, historical (non-drought tolerant) yields have been standardized by the long-term average yields in the region (*i.e.*, the mode of the probability distribution is at 100%). Because they lack information on how DT varieties perform in Ecuador, Lybbert and Carter employ stylized assumptions about the effectiveness of DT that are broadly consistent with the DTMA evidence presented in section 2.2. Note that average to above average years, which occur roughly half the time, are not shown on the graph.

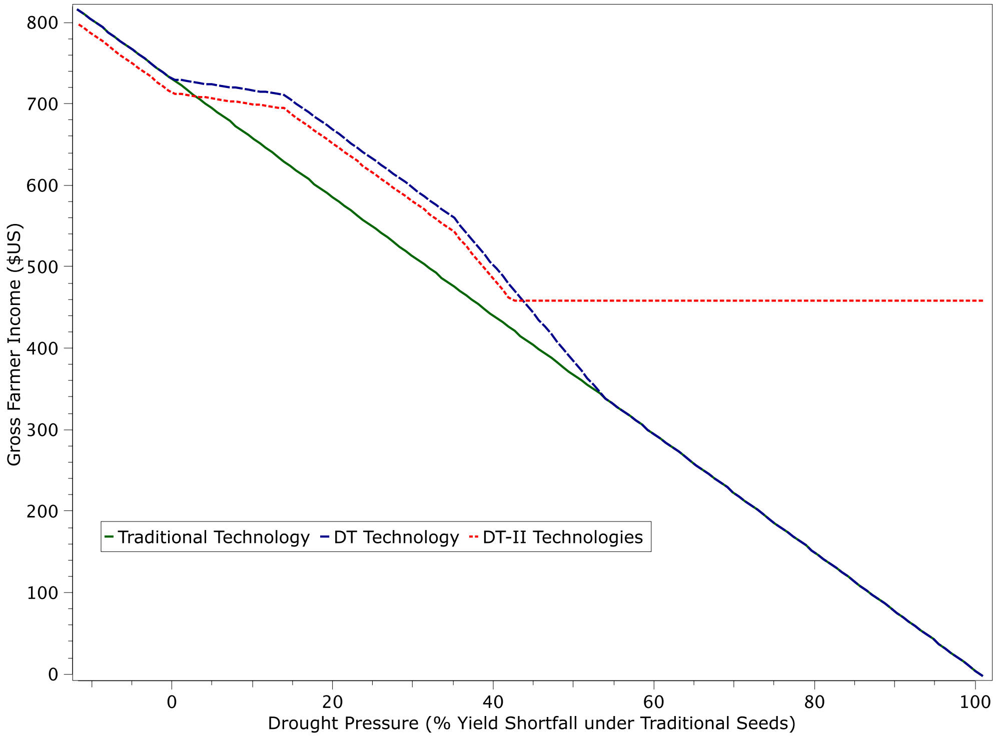


Figure 3 Bundling DT & II for Risk Management

The dashed 45-degree line in Figure 3 graphs the yield shortfall under the traditional technology as a function of itself as a benchmark. The solid line displays how DT varieties would be expected to work. Under moderate drought pressure, DT stabilizes yields at nearly their long-term expected average even as yields under the traditional technology fall up to 15%. In Ecuador, there is a 15% probability that yields will fall in this range where DT seeds offer powerful protection against drought stress.

As drought pressure increases, and the non-DT yield shortfall increases from 15 to 35% of the long-term average, DT yields also begin to slowly decline. Over this range, Lybbert and Carter assume that DT maintains a 20% yield advantage, compared to non-DT seeds. In Ecuador, there is a 20% probability that drought pressure and yields will fall in this range. Again, DT seeds substantially protect farmer yields over this range.

As drought pressure further increases, yield fall to 55% or less of their long-term average. In Ecuador, this severe drought pressure occurs 10% of the time. Over this range of severe drought pressure, Lybbert and Carter assume that the advantages of DT begin to disappear. Indeed, 5% of the time, drought is so severe that that DT yields become indistinguishable from the yields of non-DT varieties. That is, the 'red zone' occurs in Ecuador between 5% and 10% of the time.

What we see in Ecuador is that DT technology offers modest to strong protection for 80% of all drought events. However, for the 20% of events that is most extreme, that advantage dissipates, creating the space and need for a complementary stress-resistant technology. Before looking at the value of that technology for the case of Ecuador, it is important to keep in mind that in the more extreme conditions found in Africa, the fraction of drought events managed by DT will be smaller, as we have already seen in section 2.2 above.

Figure 3 displays what further benefits could be achieved with an index insurance contract that kicks in and stabilizes farmer income at those higher drought pressure levels where DT varieties lose their efficacy. The dashed (red) line displays how a "red-zone index insurance contract" would work that steps in and stabilizes farmer income at the level when DT varieties lose their ability to protect the farmer. Under this combined mechanism, farmer income never falls below the level associated with a drought that reduced yields by 40%, no matter how severe drought pressure becomes.

For the specific case of Ecuador, Lybbert and Carter (2014) go on to analyze from the farmer's perspective the relative desirability of four scenarios: (i) operating only with the non-DT varieties; (ii) operating with DT seed varieties without red zone index insurance protection; (iii) operating only with non-DT seed varieties and a comprehensive index insurance contract that covers losses for both moderate and severe drought events; and, (iv) the combined DT seed varieties with a red-zone index insurance package. Their clear finding is that option (iv) strongly dominates the other as it exploits the relatively cheap stress resistant available from DT seeds, and yet complements it with index insurance for the relatively rare red zone events. In drought-prone maize-growing regions of Africa, with larger probabilities of both moderate and severe drought pressure events, the gains from the combined DT-II package would be even larger.

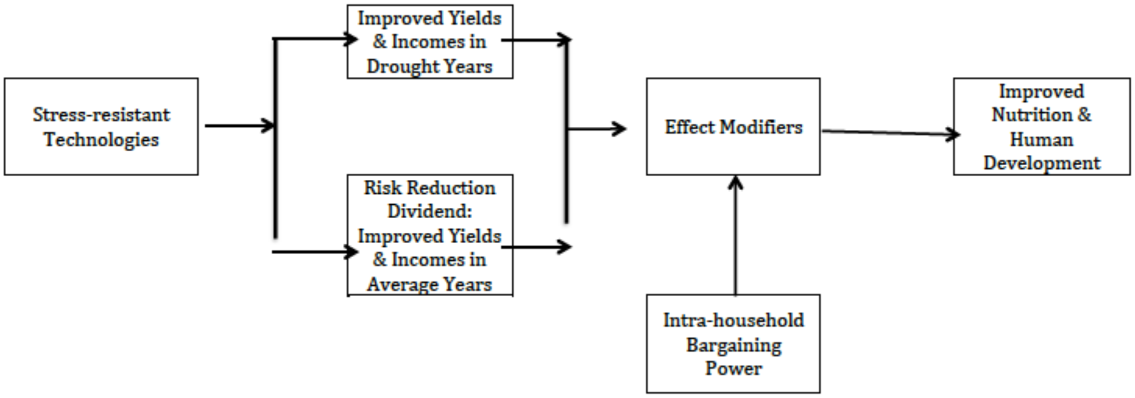
3. Study Design

The prior section has summarized what we know about the efficacy of the two key elements—drought tolerant seeds and index insurance—that we propose to assemble to study the impact of stress tolerant technologies as DT seeds are scaled up. Figure 4 summarizes the theory of change that guides the proposed study. There are three main questions that this research hopes to answer:

1. Can stress-resistant agricultural technologies improve nutrition and human development in vulnerable populations?

2. Given evidence that the impacts of income or purchasing power increases alone on nutritional outcomes can be weak on average, are these impacts amplified when women enjoy a stronger intra-household bargaining positions?

3. Does the provision of an index insurance contract that manages extreme drought events where DT seeds fail improve the uptake and impact of a stress-resistant seed technology?



Outcome Indicators	*Impact Indicators*	
• DT Adoption • Area Planted • Investment in other inputs	• Crop Yields • Income	• Dietary Diversity • Food Security • Age-appropriate Development Measures

Figure 4 Theory of Change

Note that we are *not* trying to test the effectiveness of index insurance in isolation, as our *ex ante* analysis indicates that it is not a cost-effective risk management tool compared to the bundled technologies.

Given the questions we propose to answer we propose a 3-arm randomized controlled trial compactly comprised of the following groups and sample sizes in each country:

- *Control Group (postponed treatment)*
  27 Learning zones; 2 villages per zone; 540 households in Total

- *DT Maize Group (immediate treatment)*
  27 Learning zones; 2 villages per zone; 540 households in Total

- *Bundled II and DT Maize Group (immediate treatment)*
  27 Learning zones; 2 villages per zone; 540 households in Total

Note that as stressed in the prior section, we consider II as an optional add-on that can be purchased along with DT seeds. Our prior is that the II option will boost the uptake of DT seeds and create a more comprehensive risk management package with larger impacts. It is of course also possible that II will add nothing to DT.

3.1. Target Population

In the companion Ethiopia study, we will (if funded) focus on the subset of rural households that have children under 3 years of age or women in the third trimester of pregnancy. It is children in this age bracket who are most liable to suffer irreversible consequences from nutritional shortfall.

For the work proposed here in Mozambique and Tanzania, we need in consultation with stakeholders to decide if we focus on the same population of farmers, or if we select a sample more broadly representative of the entire small-farm population.

3.2. Implementing the Randomized Control Trial

To assure study validity, we need to allocate otherwise identical individuals and communities across the 3 treatment arms listed above. We will frame our proposed randomization strategy in terms of the DT component, as that is the most technically challenging.

Because DT varieties are being scaled up and released into the market, we cannot follow the sort of simple individual randomization strategy followed by Emerick *et al.* (2014) in their study of flood tolerant rice. In the flood tolerant variety study, the research team provided, free of charge, the stress-resistant variety to randomly selected individuals in their study area. While exact details will need to be negotiated with commercial partners who will scale-up the DT varieties in Tanzania and Mozambique, we tentatively propose to follow the randomized rollout strategy employed by Carter *et al.* (2014) to study the impact of new, commercially developed and provided maize varieties in Kenya. Given the DTMass scale-up strategy, it should be relatively straightforward to implement this or a closely related approach.

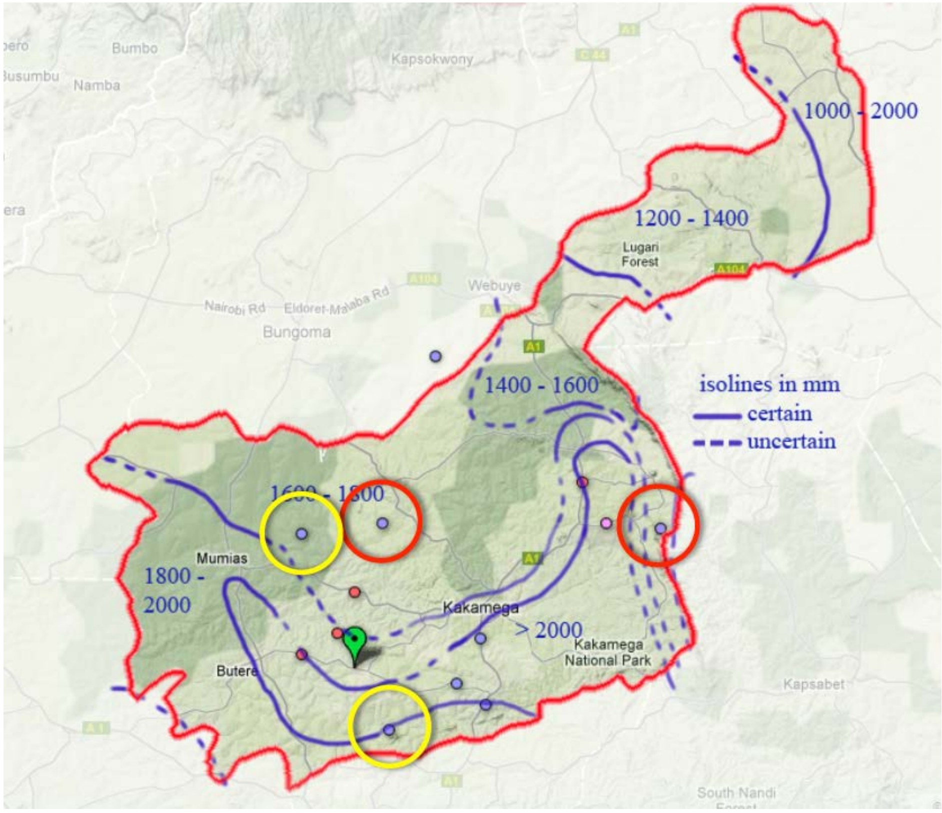


Figure 5 Matched Pair Cluster Randomization

Figure 4, taken from the Kakamega area in the Kenya study, can be used to illustrate our proposed randomization approach. As companies put new seed varieties on the market, they typically establish demonstration plots across the territory where they wish to sell the new seed. Each plot—typically established on the land of an individual farmer—is intended to inform farmers who live in close proximity to the plot and pass by it regularly. In the Kenya study, demonstration plot “learning zones” were defined as 5 km radius circles around the plots. The dots on the map in Figure 4 represent a set of potential demonstration plots identified by the seed company. For four of these points, the figure shows the associated 5 km learning zone. At the request of the research team, the company identified surplus demonstration plot locations. For example, in one region, the seed company wanted to plant 100 demonstration plots, but identified 120 potential sites. The research team randomly selected 40 of the 120 sites for the study. These 40 sites were then put into 20 matched pairs based on agro-ecological conditions (rainfall patterns, illustrated as isohyets in Figure 4 and altitude). One member of each matched pair was then randomly allocated to the control group, and the other to the control group. Figure 4 shows two sets of matched pairs, with the yellow learning zone circles allocated to the treatment group, and the red to the control group.

This “matched pair cluster randomization” design enhances the statistical power for a given clustered sample design (Imai *et al*., 2009). Within each study site, farmers were enumerated through a multi-stage strategy, and a random sample of study participants was recruited. Importantly, the seed company agreed to refrain from marketing activities in the control zones for three years. In return, the research team saturated treatment areas with additional seed information, trial seed starter seed packets, etc. In the most recent year of this study, we also took orders from farmers and delivered the seeds directly to farmers, alleviating their concerns seed quality and retail sales locations.

As soon as we have finalized the study sites, we will fine-tune our power calculations. As detailed in section 3.4 below, we here draw on power calculations for a population of farmers in a drought prone area of Western Kenya. Based on these calculations, *for each country* we will need approximately 81 learning zones. Consistent with the design laid out above, 27 of these zones will be reserved as control or ‘late treatment’ areas, while 27 will be allocated to each of the 2 treatment arms. We will interview 10 farmer households in each of two randomly selected in each zone and interview 10 households in each village, giving a total of 540 households for treatment group. To improve statistical power, individual encouragement incentives will be employed in the form of randomly distributed discount coupons for the purchase of DT seeds and DT seeds bundled with the insurance.

3.3. Outcome and Impact Variables

The bottom panel in Figure 4 abovw lists the primary outcome and impact variables to be measured for this study. Key intermediate outcome variables are simply the adoption of the improved, stress-resistant technology (*e.g*., DT seeds). Via the risk reduction dividend, we expect the adoption of stress-resistant technology to crowd-in additional agricultural investment at both the extensive margin (area planted) and the intensive margin (investment in yield or value increasing inputs).

Further along the causal chain, we also expect intermediate impacts on both farm yields and real incomes, especially in years of drought. Finally, our bottom line impact indicators are those related to nutrition and human development. We will also explore impacts on measures of dietary quality, including diversity as well as standard food security measures.

Finally, and for reasons discussed more in section 4 below, we will directly measure intra-household bargaining power as well as pre-determined factors that predict intra-household bargaining power.

3.4. Power Calculations

We here base our proposed sample design on parameters estimated for the small farm, maize-growing population in a drought-prone region of Western Kenya. We will later revisit these calculations with parameters derived from our proposed Tanzania and Mozambique study areas, once those areas have been finally selected. The numbers presented here should be a quite reliable guide to what we can expect in our proposed study area.

Figure 6 displays the results of our power calculations. MDEs are shown for 80% power assuming hypothesis testing is done with a 5% Type-I error probability. In a study of agricultural technology, one of the key parameters (and uncertainties) is the net compliance rate, defined as the difference between the percentages of individuals in the treatment group who adopt the technology minus the percentage in the control group who does the same. We here assume that we can achieve a net-compliance rate of 50% (e.g., 70% of farmers in the treatment area adopt the DT seeds, while only 20% of those in the control area do).

To calculate these MDE's, we utilized the TARPA panel data set collected and maintained by the Tegemeo Institute in Kenya. The two figures below illustrate the sample sizes needed to reliably detect impacts of hybrids in the Kenya study. The horizontal axis of each figure shows the total sample size for any two-block comparison (e.g., DT treatment versus control in our case). In simpler terms, dividing the number on the horizontal axis by 2 reveals the number of households that need to be surveyed in each of the four distinct groups identified in Table 1 above. The analysis assumes that households are sampled in village clusters, with 10 households surveyed in each village.

Figure 6 shows the results of this analysis. As can be seen, with a sample size of 533 households per-treatment block (or just over 1000 in total for a two block comparison), we should be able to detect yield effects as small as 10% and income increases as small as 15%. Given the expected impacts of our study technologies, minimum detectable effects (MDEs) of this magnitude are quite reasonable. In other words, if impacts are less than these amounts, then we are unlikely to consider the technologies a success. If the impacts are larger, we will definitely have the power to detect them. This sized sample also gives us headroom in the event that we achieve less than a 50% net-compliance rate.

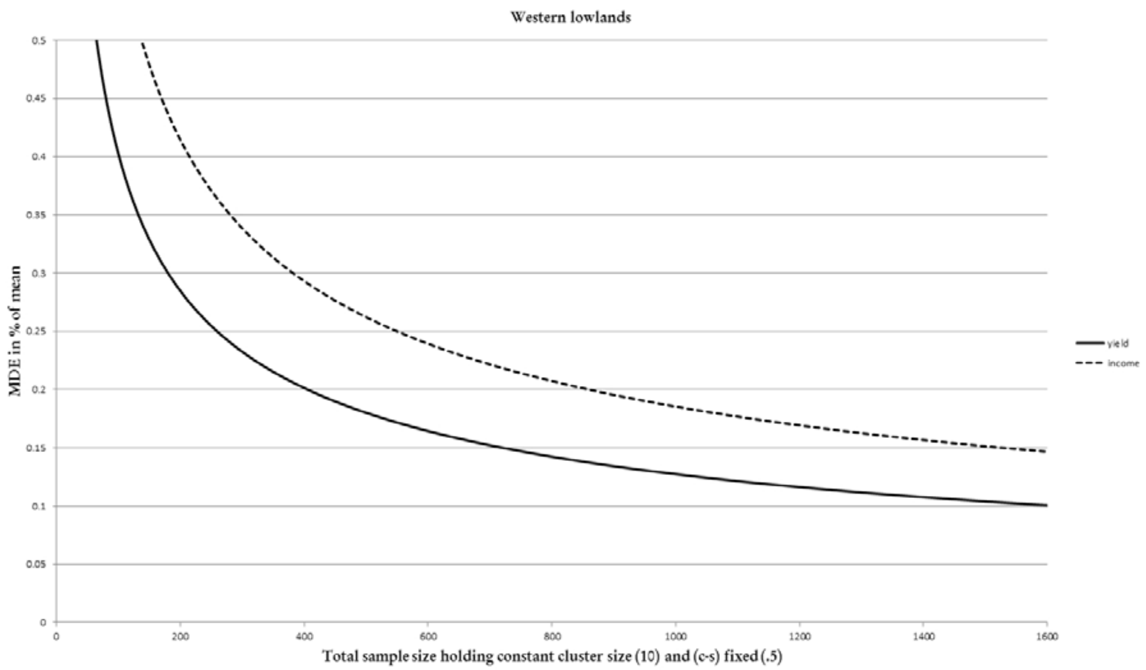


Figure 6 Minimum Detectable Effects

4. Gender Considerations

With important exceptions, the technologies we propose to test are similar to other agricultural interventions in that their impacts are shaped by the position of women in the household food production and consumption nexus. Field observations in our study areas indicate that women typically carry primary responsibility for key agricultural tasks. Where there is strong gender-casting of tasks, technologies that boost production may place additional demands on women's already scarce time. While this increased labor time may come at the cost of less time for household and child-rearing tasks and/or less earning of independent, off-farm income, women may in some instances enjoy control over the additional agricultural production and income generated with the new technologies. If we assume gendered preferences (*e.g.*, that women care more about nutrition and child health outcomes than do men), then these tradeoffs can create either a positive feedback loopback (nutritional impacts of a given technological change are multiplied because women's effective income control is enhanced), or a negative feedback loop (women's bargaining power is undercut by the new technology).

While the above statements could be applied to almost any agricultural technology, the technologies that we propose to test are primarily intended to reduce risk and secondarily to increase mean outcomes (through the risk reduction dividend). There is both evidence that women are more risk averse than men and that women care more than men about certain outcomes that are highly vulnerable when incomes drop, such as child health, education and nutrition (Quisumbing *et al.*, 1995). A safer technology bundle should therefore differentially benefit women relative to men. Examined from the perspective of standard bargaining models of intra-household resource allocation, risk-reducing technological change should therefore empower women relative to men. If this perspective is correct, then the likelihood of a positive feedback loop is increased.

Experimentally manipulating social norms about work or control over agricultural income is clearly not possible, but we can measure and analyze intermediate outcome variables such as women's labor time and off-farm earnings. At a deeper level, we propose to measure the impact of the program on intra-household bargaining power by building on the methods pioneered by Ashraf (2009). Finally, should the companion proposal to study DT in Ethiopia be approved, we will able to see the impact of a nutrition education intervention (seen as something that shifts the intensity of preferences for nutrition) with the technology intervention, giving us another degree of freedom that we can use to explore how gender preferences and power shape the link between agricultural interventions and nutrition.

5. Program and Policy Implications

At its most general level, the research proposed here is designed to speak to the global discussion about the wisdom of investing in agriculture as a mechanism not just to produce more food, but as a cost-effective mechanism to address undernutrition. In looking specifically at investments in stress resistant technologies, the work proposed here—if it indeed finds that investments in stress resistance is effective—will offer a new and we hope important perspective on how governments, aid agencies, foundations and other donors should shape their investment strategies.

Stepping back from this global discussion, the evaluations of the interventions proposed in this study may have important implications for the design of programs and policies in rainfed maize regions of Sub-Saharan Africa. If bundling DT maize varieties with II has the anticipated effects on nutrition and household income resilience, the project will provide a way to extend the reach of DTMA investments by making the DT maize portfolio relevant for even marginal maize regions. Early on, DTMA shifted its focus away from these regions and to regions with less severe drought risk because of the 'red zone' risks described above. Effective bundling with II may enable DTMA to bring these regions back into its focus in the scaling up activities planned to begin in 2015. In the more favorable regions that are currently targeted by DTMA, effective bundling may have an intensification benefit via the risk-reduction dividend. On either the extensive or the intensive margin – or both – findings from this project could magnify the effects of DTMA investments on rural farm households.

There are practical considerations associated with bundling DT and II that may have implications for the design of other programs and policies. Scaling up such a bundle may require supporting institutions and other investments in the financial system, including continued innovations to facilitate rural households' access to financial services, such as mobile money and other ICT-based services. To be practical, DT-II bundles must simplify as much as possible farmers' purchase decision. This will similarly require continued innovation of input delivery platforms in collaboration with agro-input dealers and networks, which may open new possibilities for deepening and enhancing input supply chains.

To the extent that DT-II bundles protect smallholders from potentially devastating consumption shortfalls during severe drought, the results of this project have implications for the design of humanitarian responses. A critical mass of farmers benefiting from DT-II bundles would extend the reach and efficacy of limited humanitarian response resources. Moreover, these bundles provide resilience to drought in a way that might more favorably affect local markets, and these local market effects might be leveraged by improved humanitarian responses.

In addition to testing this *ex post* drought protection benefit, our research design will enable us to detect the 'risk-reduction dividend' associated with DT-II bundles. Evidence of this dynamic effect on smallholder farmers implies that the project may change farmers' input investments more broadly. This could have important effects on local demand for improved agro-inputs and services. With complementary public and private sector investments developing these supply chains, this increased local demand could catalyze the kinds of market linkages that are essential to agricultural productivity gains and ultimately structural transformation of rural economies.

6. Country Selection

It is important to stress that the work proposed here is being developed in full collaboration with CIMMYT and DTMA. Working with these organizations, we sough out three characteristics for target countries: (i) Good seed company partners, (ii) Locations where maize is an important crop and an important part of the basic diet, and (iii) Spatial and climatic variation across the study area to increase the probability of observing drought events within the 4 years of the study.

Based on these three criteria, the research team has tentatively selected Tanzania and Mozambique for this work. According to FAO data, Tanzania has the second largest area in Africa planted to maize (second only to Nigeria), making this country selection particularly important for our study. Tanzania also has substantial unmet potential; over the last decade, maize yields have barely exceeded 1 ton/hectare. As part of the DTMass project, Aminata Seed intends to market its three DTMA varieities in 13 or Tanzania's 21 regions. The Tanzanian RCT will focus on a sub-sample of Aminata Seed Company's intervention regions and districts: Tunduru district in Ruvuma region and Masasi district in Mtwara region. Under its DTMass targets, Aminata Seed aims to have 9,000 farmers cultivating 1,500 hectares of the company's DTMA maize seed in Masasi district. In Tunduru district, they are targeting 7,500 farmers and 1,800 hectares. These uptake figures are based on the assumption that 50 percent of farmers who receive free seed packets will purchase and utilize the seed at scale. We anticipate enrolling a total of 1600-2000 farmers in the RCT study, or about 12.5 percent of targeted farmers in the study areas. We will be fine-tuning our power calculations and finalizing our study design in the near future.

While we do not yet have full information on the planned Mozambique scale-up, we know from DTMA that, like Tanzania, it is a promising area for our study as existing maize yields are quite modest, meaning that the expected impacts of our proposed technologies should be quite large. Mozambique has a very different seasonality than most parts of Tanzania (with independent weather patterns).

CIMMYT has agreed to use the funds that it has allocated for impact study of the DTMass program in Mozambique ($155,000) and Tanzania ($190,000) can be used to fund the DT-only and control arms of our proposed study. In addition, CIMMYT scale-up funds will also be available to defer extraordinary roll-out costs that may be experienced by participating seed company partners (*e.g.*, so that free trial seed packets can be distributed to study farmers). Our budget request here is net of these contributions.

7. Seed Company Partners and Next Steps

DTMass is moving quickly. Our collaborating investigator, Dr. Monica Fisher of CIMMYT, attended the DTMass launch in Tanzania in January 2015. This meeting gave Dr. Fisher an opportunity to interact with a Tanzanian seed company that we have tentatively selected for this study. Subsequent to that meeting, in follow-up discussions with Aminata Seed Company, the company tentatively agreed to participate in the study.

This company was selected in consultation with Dr. Tsedeke Abate, Director of the DTMA program. Aminata Seed Company has high quality DT seeds ready to market, and is run by dynamic individuals likely to fully appreciate the value of the proposed research. This company is also incorporated into the DTMass scale-up plan, with their marketing of the DT varieties scaling up over the next 4 seasons. We believe it will be an easy ask to have them randomly select some of the proposed areas where they will scale-up for late (year 4) treatment. The late treatment of these areas (which will in any event happen in some areas) will allow our study to have a natural control group. Similarly, we will also ask the company to randomly select some areas for early (year 1) treatment. Because these are modest asks, and because our research activities should actually accelerate the adoption of their products, we do not anticipate any difficulties achieving their cooperation with our study.

In Mozambique, our CIMMYT collaborator, Dr. Rodney Witman Lunduka has identified two seed company representatives to attend a planning meeting in mid-March 2015 to discuss the possibility of collaborating on combining a RCT with the DTMass launch in Mozambique:

- Elizabeth Sikoyo from SementeNzaraYaPera
- Julius Mapanga from Klein Karoo

8. Insurance Design and Partners

BASIS-I4 has taken a deep dive into the use of sophisticated satellite measures (evapotranspiration, gross primary production, green leafy area indices, etc.) to predict crop yields in Tanzania. We have also worked with insurance providers in Tanzania, and anticipate no problem in lining up commercial providers for high quality index insurance products.

While our research team has substantial experience in Mozambique (most recently a study of improved maize seeds and fertilizers in Manica province), we have not yet worked on agricultural insurance in this country. However, we are in touch with FAO insurance work in that country and will be able to hit the ground running in terms of an insurance design and commercial implementation.

Similar to the work with private sector seed companies, the proposed work on insurance is designed to facilitate the growth and sustained presence of private insurance providers. The budgets below include funds for contract design, educational activities and 'trial' insurance contracts, which, like seed packets, are intended to build learning and long-term market demand.

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