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Using Index Insurance to Promote Climate-Smart Agriculture

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Abstract

Climate change is resulting in an increased frequency and severity of droughts in countries such as Senegal and Ethiopia. For smallholder farmers who are dependent on rainfed agriculture and have limited protection from climate impacts, climate change has the potential to devastate livelihoods, perpetuating the cycle of poverty in rural communities.

Climate-smart agriculture offers the potential to increase the adaptive capacity of farmers while increasing incomes. However, climate-smart investment entails risks and costs that oftentimes risk-exposed farmers are unwilling or unable to manage.

Along with climate-smart agriculture, index-based insurance has attracted considerable attention and shown promise as a tool to help reduce investment risk. The two work in complementary ways, and insurance has the potential to reduce investment risk under certain conditions. The conditions under which insurance incentivizes climate-smart investment, however, have not been adequately addressed in the existing body of literature.

Informed by lessons learned from two projects in Senegal and Ethiopia, we posit that the appropriate combination of tools for reducing investment risk depends on a range of factors, including 1) weather and basis risk, 2) the technology's cost, profitability, and protection, and 3) risk exposure and loss.

We developed an interactive risk analysis framework that simulates the farmer's decision-making process for various investment options given a set of parameters, using stylized inputs based on approximate costs and prices for a smallholder farmer in Senegal. The model confirms that insurance's ability to de-risk investment depends largely on the interaction between the three aforementioned factors. At lower levels of climate risk, farmers may not need both technology and insurance to cover productive risk. In such a case, subsidizing technology rather than insurance may be more effective. At higher levels of climate risk, farmers may need both technology and insurance to manage productive risk. Under these conditions, it may be better to subsidize insurance rather than technology, and insurance may function to mitigate the residual risk that technology is unable to mitigate.

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Acronyms and Abbreviations

CSA	Climate-smart agriculture
EPIICA	Ethiopian Project on Interlinking Insurance with Credit in Agriculture
FFA	Food for Assets
IFA	Insurance for Assets
PI	Productive Investments
R4	Rural Resilience Initiative in Senegal
SFC	Savings for Changes

Executive Summary

Climate change is resulting in an increase in weather variability and global mean temperatures, with disparate impacts on farmers around the world. In countries such as Senegal and Ethiopia, climate change is resulting in an increased frequency and severity of droughts. For smallholder farmers who are dependent on rainfed agriculture and have limited protection from climate risk, climate change has the potential to devastate livelihoods, perpetuating the cycle of poverty in rural communities.

Climate-smart agriculture (CSA) offers the potential to increase the adaptive capacity of farmers while increasing incomes. CSA is an integrative approach that addresses the interlinked challenges of food security and climate change (CCAFS and FAO, 2014). We define CSA as agricultural practices that 1) increase agricultural productivity in a sustainable manner, 2) build the resilience of farmers and food security systems to climate change, and 3) reduce green gas emissions from agriculture. In addition, climate-smart technologies may offer additional co-benefits such as a reduction in pollution, water use, and land degradation. CSA technologies vary in terms of how much they increase resilience and productivity: some increase resilience more, while others increase productivity more.

Climate-smart investment entails risks and costs that farmers are oftentimes unwilling or unable to manage. Reducing the risk of investment is therefore imperative to incentivizing farmers to invest. Despite the fact that climate-smart technologies offer some degree of embedded protection against climate risks, these technologies are unable to mitigate all risk.

Insurance may serve to fill this gap, especially at high levels of climate risk. Climate-smart technologies and insurance work in complementary ways to help farmers manage climate-induced investment risk, although the combination of tools that most effectively helps farmers manage risk depends on the level of climate risk and a range of other factors.

Under certain conditions, insurance helps farmers manage some level of investment risk by stabilizing incomes and facilitating access to credit, which may promote investment in climate-smart technologies. In turn, the increased revenue from these technologies helps farmers pay for the insurance. In the long run, insurance may help farmers increase incomes while protecting them against increasingly frequent and severe droughts.

However, the conditions under which insurance incentivizes climate-smart investment have not been thoroughly explored in the existing body of literature. Existing literature on agricultural index-based insurance has focused predominantly on the means of expanding its coverage. This paper seeks to reframe the narrative around index-based insurance by examining the conditions under which index-based insurance promotes climate-smart agriculture by de-risking investment.

Informed by lessons learned from previous cases in Senegal and Ethiopia, we identified key exogenous variables that affect index-based insurance's ability to facilitate climate-smart investment. We refer to these factors as *switch factors*. These factors include 1) weather and basis risk, 2) technology's cost, profitability, and embedded protection against climate risk, and 3) risk exposure and loss. The interplay between these factors has crucial implications in insurance's ability to foster climate-smart investment.

We developed an interactive risk analysis framework that simulates the farmer's decision-making process for various investment options given a set of parameters, using stylized inputs for a smallholder farmer in Senegal. These parameters can be modified to help determine the investment options that bring about the largest benefit to farmers in other contexts. The model confirms that insurance's ability to de-risk investment depends largely on the interaction between the switch factors.

This framework serves to help project proponents and policymakers gain a better picture of the potential impact of insurance programs prior to their rollout and make more strategic decisions about interventions designed to increase climate-smart investment among smallholder farmers. The framework may also help governments assess the most effective use of limited funding.

Based on the model, we arrived at the following conclusions:

1. At low to moderate levels of climate risk, insurance may have limited use to the farmer, as the climate-smart technology is able to mitigate the risk. Subsidizing technology may be more effective at low to moderate levels of risk.
2. At high levels of climate risk, insurance may be necessary to cover tail-end or residual risk, as the climate-smart technology is unable to mitigate all risk. Subsidizing insurance may be more effective at high levels of climate risk.
3. Credit availability enables farmers to invest in climate-smart technologies. Ensuring access to credit is therefore an important part of any effort to increase investment.

4. Since technologies vary in terms of their potential productivity gains and embedded protection to climate risk, calibrating insurance indices to specific technologies may work to reduce basis risk.

Our analysis is also subject to several additional considerations:

1. Technologies fall on a spectrum in terms of the degree to which they are climate-smart. There are some technologies that are neither strictly climate-smart nor conventional; rather, they fall in between these two categories.
2. There is a possibility that climate impacts become so severe such that neither insurance nor climate-smart technologies will be able to mitigate all risk. This may result in farmers seeking out other sources of income or places to live. In such a case, government funding may be used to facilitate the transition to other economic sectors, migration to other areas, or the development of improved technologies.
3. There may be some intermediary solutions that project proponents need to consider. For example, existing weather monitoring systems and financial institutions may need to be strengthened first in order to implement index insurance programs that promote climate investment. These intermediary solutions fall outside the scope of our paper and model.
4. The risk analysis framework considers net financial benefit from the perspective of an individual. A macro-level analysis that considers both negative and positive externalities is important to capturing the full economic benefits of any project or program. Subsidies and regulation may serve to correct any market distortions.

This report serves to help project proponents and policymakers make more informed decisions when designing interventions aimed at improving the livelihoods of smallholder farmers in the face of climate change. Although the report frames the analysis in the context of Senegal and Ethiopia, the power of the interactive risk model lies in its ability to be modified to suit the needs of policymakers and project proponents worldwide.

1. Introduction

1.1 Research Gap: Reframing the importance of insurance

Many policymakers, researchers, and project proponents have assumed that insurance reduces vulnerability and increases productivity among smallholder farmers in developing countries. However, insurance is not a panacea for the problems that smallholder farmers face due to climate change. Little research has been devoted to the conditions under which insurance is able to de-risk agricultural investment and bring about a net benefit to the farmer.

In the last decade, research on index-based insurance has primarily focused on barriers to increasing its scale and uptake (Hazell et al. 2010, Binswanger-Mkhize 2012, Greatrex et al. 2015, Sibiko et al. 2017, Vasilaky et al. 2020). There has also been some research on the factors key to the success of insurance schemes, such as weather variability, basis risk, and cost.

Jenson, Barrett and Mude (2016) examine the quality of index-based livestock insurance in Kenya and conclude that farmers are left with an average of 69% of their original basis risk due to severe weather events. This suggests that basis risk significantly alters the risk mitigation potential of index-based insurance. Nevertheless, the article does not assess the level of basis risk at which index-based insurance no longer provides added value to the farmer.

Adegoke, et al. (2017) examines index insurance's ability to promote sustainable intensification within agricultural systems, concluding that insurance coverage encourages farmers to invest more and take on more risk. However, high premium costs were found to negatively impact the de-risking potential of index-based insurance. As cost is relative, how variation in cost affects the de-risking potential of insurance remains unclear.

Vargas, et al. (2019) concludes that index insurance can encourage investments in riskier production and help mitigate the costs of coping with weather shocks. They find both ex-ante and ex-post impacts on productive investments. In terms of ex-ante effects, they find that pure risk management results in higher expenditures on agricultural inputs in seasons with a high number of weather-related shocks. These expenditures include fertilizer, hired labor, irrigation, and pesticides (Vargas, et al., 2019). In terms of ex-post impacts, they find that insurance coverage results in increased income or liquidity, mostly as a result of the insurance payout (Vargas, et al., 2019).

While clearly relevant, these examples demonstrate the lack of research on the conditions under which index insurance de-risks climate-smart investment. In this paper, we aim to address this research gap by reframing the conversation around the impact of insurance by focusing on the conditions under which insurance de-risks investments in climate-smart agriculture.

1.2 Linking insurance to CSA investments

Climate change is resulting in an increased frequency and severity of droughts in countries such as Senegal and Ethiopia. For smallholder farmers who are dependent on rainfed agriculture and have limited protection from climate impacts, climate change has the potential to devastate their livelihoods, perpetuating the cycle of poverty in rural communities. Oftentimes, smallholder farmers in developing countries are constrained by several limitations that hinder their ability to invest, and climate change can exacerbate these limitations.

Climate-Smart Agriculture (CSA) offers the potential to increase the adaptive capacity of farmers while increasing their incomes. CSA is an integrative approach that addresses the interlinked challenges of food security and climate change (CCAFS and FAO, 2014). The main features of CSA technologies are 1) increase agricultural productivity, 2) boost resilience to climate change and 3) reduce the impacts of agriculture on the environment (World Bank, 2019). Such CSA technologies include, for instance, drought-resilient seeds, drip irrigation, the use of satellite imagery to forecast weather conditions, and remote sensing to apply the right amounts of fertilizer and pesticides on crops. CSA technologies vary in terms of how much they increase resilience and productivity: some increase resilience more, while others increase productivity more.

In light of climate change and increasing weather variability, the promotion and adoption of CSA brings several benefits that can enhance sustainable agricultural productivity in the long run. However, investments in CSA can entail risks that oftentimes risk-exposed farmers are unwilling or unable to manage. Insurance may serve to fill this gap, especially at high levels of climate risk.
The focus of this report lies on index-based insurance because its design is tailored to meet the needs of rural smallholder farmers more accurately than traditional forms of insurance like indemnity insurance. For instance, reporting losses for indemnity insurance is generally complicated and not possible for remote rural farmers. Additionally, index-based insurance has proven to be an appropriate measure to compensate smallholder

farmers for losses based on area-yield or weather-based indices in light of limited acreage and increased climate variability (Kath et al., 2018). Moreover, under some circumstances, fostered by index-based insurance, a farmer might be drawn to invest in CSA to further protect herself against these challenges and to bump her production

Finding a way to de-risk investments is imperative and index-based insurance has shown promise as a tool to achieve this. Nonetheless, the conditions under which insurance incentivizes CSA investment have not been adequately addressed in the existing body of literature. This report will delve deeper into understanding long-term impacts of insurance schemes to identify the factors that levy investment potentials in CSA. With this analysis, we aim to bridge the gap that policymakers generally face due to limited data availability on this matter.

1.3 Investment Decision Framework

The farmer is the main stakeholder in this process and therefore, it is crucial to understand her thinking process. For a farmer, as for every human, life is a series of events and she will make investment decisions based on the occurrence and severity of events that alter production outcomes.

Let us assume a scenario in which a smallholder farmer in Senegal does not follow an investment strategy, she is dependent on rain-fed irrigation and uses basic seeds. As long as there are no climate risks, this procedure is profitable and the farmer derives sufficient benefits. But when a weather disaster occurs, for instance a drought, the farmer is highly exposed to its effects, losing a high share of the crops, if not all. Based on the frequency and severity of the weather disasters, the farmer may decide to invest in risk management strategies in order to increase her crop's resilience and to safeguard profits. Thus, the occurrence and the severity of an event, reflected in the yield loss, have the potential to alter the farmer's investment decisions.

The selection of a risk management strategy can vary depending on the farmer's needs and investment capabilities. In order to select the most appropriate approach, the farmer most consider some key factors, such as 1) the frequency and severity of weather disasters, 2) the expected loss from each disaster, 3) the increased cost needed to bear to protect herself, 4) selection of a technology that increases production, 5) the resilience of this technology to climate impacts, and 6) whether insurance can complement the gaps from such technology, among others.

In the farmer's investment decision framework, these considerations are portrayed as four switch factors or decision-making variables that can influence a farmer's investment decisions. We will explore these switch factors in the following subsection.

1.4 Three layers of Switch Factors

We define switch factors as the exogenous variables that influence if and when index-based insurance facilitates CSA investments. Index-based insurance can act as a catalyst for triggering these switch factors, providing the last push to invest in CSA. The report will analyze these switch factors, which are: 1) weather and basis risk, 2) technology, and 3) risk exposure and loss. As a deep understanding of these switch factors is of utmost importance to assess the impact of index-based insurance, the following subsections will provide an in-depth description of the three determinants.

1.4.1 Weather and Basis Risk

The first switch factor category describes the interplay of climate risk and basis risk. The interplay between both factors plays a crucial role in determining the impact of index-based insurance on productive investments in CSA.

Agricultural production is vulnerable to various sources of risk, one of these is related to the frequency and severity of weather-related shocks. Frequency and severity refer to how often and intense weather-related shocks occur in a specific region. As the frequency and severity of weather-related shocks continue to grow, so do crop failures, which directly affect the smallholder farmer's productivity, livelihood, and decisions. This report analyzes the frequency and severity of weather-related shocks portrayed as less rainfall.

Basis risk refers to the mismatch between the weather index and the actual loss of a farmer (Gaurav and Chaudhary, 2020). Basis risk is most common in developing countries, due to the lack of sufficient data for large-scale agricultural insurance programs, low investments in new technology, cleaning of data, and infrastructure (Boudreau, 2010). When combined with other factors, such as lack of trust in the insurance provider, limited liquidity, and lack of familiarity with the insurance principles, the demand for index-based insurance can be constrained (Vargas et al., 2019). In the context of this report, basis risk is measured by the probability of a payout in a bad year.

The interplay of climate and basis risk is reflected in the overall probability of receiving a payout depending on the frequency and severity of climate events; it is crucial to highlight that these payouts only occur in bad years. The combination of the two factors can alter the farmer's ability to invest. The interaction can be portrayed as follows:

- In the event of consecutive goods years and no insurance payouts, a farmer is more financially constrained with insurance than without insurance due to premium payments. Thus, her ability to invest in climate-smart technologies is negatively impacted and the additional value of the insurance is limited with or without basis risk.
- In the event of consecutive bad years with low basis risk, the farmer benefits from index-based insurance. Furthermore, the additional income from insurance payouts enables her to invest, for instance, in climate-smart technologies to increase productivity and protection against climate risks.
- In the event of consecutive bad years with high basis risk, index-based insurance puts a financial burden on the farmer. The higher the frequency of bad years, the more the farmer is exposed to the potential negative impact of inaccurate payouts. In this scenario, the farmer's ability to invest decreases significantly.

The interplay of climate and basis risk directly influences the de-risking potential of agricultural index-based insurance and is an important consideration to assessing costs and benefits.

1.4.2 Technology: Cost, Profitability, and Protection

The second switch factor relates to objectives of technology; its cost, profitability (yield) and protection (less severity of a bad year). This section specifically examines the point at which a cost-yield combination enables insurance to promote investment in CSA.

The prospect of investing in CSA is primarily driven by cost considerations. The higher the cost of a CSA technology, the less likely the farmer is to invest with or without insurance. The cost of CSA can be significant, especially when investing in long-term CSA technologies such as drip irrigation. As most farmers have limited access to credit and are financially constrained, high costs can preclude investments. To overcome financial constraints, the farmer has the option to borrow by taking up loans. It is evident that a loan comes at an additional cost and risk. Furthermore, if a farmer cannot repay the loans and has to take up an additional loan, these expenses have to be added to the original cost.

Nevertheless, CSA carries two main benefits: increased profitability (reflected in increased yield) and embedded protection (reflected in less severity of a bad year). For instance, the implementation of drip irrigation might be costly, but it increases the overall yield in bad and good years due to efficient and constant use of water. In bad years, the technology provides high protection against droughts due to the embedded protection of the CSA technology. Thus, the embedded protection is a technology's ability to help farmers withstand climate shocks. Only under very severe droughts (e.g. when water tanks run dry) the farmer is still exposed to climate risks. Thus, to determine the benefit of a technology, the overall cost-yield relationship and the decreased exposure to climate risk need to be assessed.

For the purpose of this paper, it is important to note that governments can subsidize CSA at different levels - by subsidizing CSA technologies directly or subsidizing index-based insurance schemes. Further, it is of particular interest to assess how subsidizing an agricultural index-based insurance scheme impacts the CSA technology investment behavior of smallholder farmers. To understand when subsidizing index-based insurance is beneficial, it is necessary to compare its costs and benefits with those of other agricultural input subsidies.

1.4.3 Risk Exposure and Loss

Our last switch factor is risk exposure and loss. Risk exposure influences how much a farmer will invest in insurance and in CSA, or in both. In this report, risk exposure is portrayed as the subsequent cost of going negative and is measured through the penalty that will be levied in such cases. Said penalty can impact the farmer in the long term, affecting her food security, educational options, and job prospects. Therefore, the higher the penalty, the more risk-exposed the farmer will be.

The interaction between risk and loss can be portrayed as follows:

- The farmer has high levels of risk exposure because of the long-term impacts of the high penalties for going negative.

- The farmer is more likely to invest in insurance to further protect herself, which at a certain threshold, might act as an enhancer for CSA investments. This increases the farmer’s embedded protection.

Ultimately, if the farmer’s level of risk exposure is above a certain threshold, the farmer is likely not to invest in a costly product irrespective of the cost-yield combination of the investment. Thus, it is crucial to examine at what threshold index insurance promotes these investments.

2. Case Studies

In the following chapter, we examine two case studies from Senegal and Ethiopia, respectively, that demonstrate the need for a framework to analyze the risk mitigation potential of index-based insurance programs. Both case studies point to important linkages between insurance and climate-smart investment, but important knowledge gaps remain. The studies were conducted in specific contexts, and it is unclear whether insurance brings about a net benefit in other contexts. A more comprehensive risk model framework is thus needed in order to answer the following question: under what conditions does insurance promote climate-smart investment?

We begin by providing a brief introduction to the two cases, followed by a more detailed analysis through the lens of the three switch factors.

2.1 R4 Rural Resilience Initiative in Senegal

The R4 Rural Resilience Initiative (R4) is a comprehensive project aimed at improving the resilience and food security of vulnerable smallholder farmers in the face of increasing climate risks. The project's name refers to the four integrated risk management strategies that it incorporates: 1) risk reduction, 2) risk transfer, 3) risk reserves, and 4) risk-taking (Dalberg, 2016).

The project adopts two approaches to delivering insurance products. The first approach is providing insurance coverage in exchange for an in-kind contribution, namely labor for risk reduction projects. The second is offering insurance plans bundled with financial support through savings associations. Most insurance products are based on weather indices that use satellite and weather station data. As required under Senegalese law, R4 in Senegal includes insurance subsidies, while R4 in other countries does not.

An impact evaluation of the R4 project showed that project participants were more capable of managing risk and investing in assets to build resilience (Dalberg, 2016). The project also resulted in increased awareness on the benefits of insurance on securing household productive investments, minimizing the impact of shocks, and strengthening the ability of households to rebound.

The evaluation was conducted under a set of conditions characterized by 1) exposure to droughts and considerable weather variation, 2) heavy reliance on rainfed agriculture, and 3) relatively low utilization of climate-smart technologies. However, it is unclear whether the results of the evaluation are externally valid. It is thus necessary to analyze whether or not insurance enables farmers to de-risk investments and increase CSA investment in different contexts.

The following subsections examine the R4 project through the lens of the three switch factors mentioned in Chapter 1.

2.1.1 Weather and Basis Risk

The focus regions of the R4 project in Senegal - Tambacounda, Kaffrine, and Kolda - are characterized by their heavy reliance on rain-fed agriculture and poverty rates higher than the national average. Climate change is resulting in an increased frequency and severity of droughts, posing a threat to the livelihoods of farmers in these regions. As climate impacts worsen, tools such as climate-smart technologies and insurance may serve to help farmers mitigate productive risk. The model outlined in Chapter 3 helps policymakers determine what combination of tools will most benefit farmers.

Basis risk is another major concern of smallholder farmers. When farmers experience a mismatch between index measurements and actual losses, they become less willing to purchase index insurance in subsequent years. The R4 project in Senegal actively uses satellite data sources and various validation processes in its index design in order to minimize basis risk. The risk model framework outlined in Chapter 3 models how variation in basis risk affects insurance's benefit to the farmer.

2.1.2 Technology

The R4 in Senegal project shows that insurance, bundled with other financial support, helps farmers increase investment in technologies. According to the assessment results, the saving capacity of R4 participants is three times higher than non-beneficiaries, and 37 percent of participants used savings to invest in income-generating activities. In terms of credit, 39 percent of participants accessed loans and invested 40 percent of this amount in productive investments (Dalberg, 2016). Possessing insurance enabled families to increase their technological investment with the assurance that, even in the case of disastrous shocks, insurance payouts would compensate for any potential loss. The increased profitability from these technologies may then be used to pay for the insurance. However, whether insurance is even necessary may depend on the level of embedded protection that a given technology offers, as well as the cost and profitability of the technology.

Among insured farmers, 8,401 of them paid 10-15 percent of the insurance premium, and the remaining 844 paid the premium in full (WFP, 2018). Further analysis is needed to determine how changes in productive investment differ between farmers with subsidized and unsubsidized insurance premiums. Furthermore, additional analysis is needed to determine the trade-offs between subsidizing insurance and subsidizing climate-smart technologies directly in the context of this project.

2.1.3 Risk Exposure and Loss

The risk transfer component of the R4 in Senegal demonstrates how CSA investment and insurance work together to reduce farmers' risk exposure and losses.

To improve the resilience of farmers against climate shocks, some project participants received insurance coverage after providing an in-kind contribution. This in-kind contribution took the form of labor for resilience-building activities, including but not limited to the creation and maintenance of nurseries for vetiver plants, the construction of dikes and stone barriers, and the construction of dams and vegetable gardens.

Under this design, the community assets themselves are the first line of defense to protect farmers from climate impacts and extreme weather events. Working on building those assets provides farmers with a second line of defense: insurance, whose payouts make farmers more resilient as the frequency and severity of extreme weather events increase.

Based on the results of the impact assessment, R4 project participants experienced greater increases in average household production of staple crops than non-participants. Participants are also more active in increasing their use of fertilizer and improved seeds to limit potential losses from shocks. Further analysis is necessary to determine how variation in risk exposure affects insurance's ability to promote investment.

2.2 Ethiopian Project on Interlinking Insurance with Credit in Agriculture (EPIICA)

The Ethiopian Project on Interlinking Insurance with Credit in Agriculture (EPIICA) examined the conditions under which insurance promoted agricultural investment among drought-exposed farmers in 120 villages in Amhara State, Ethiopia. While the case points to some important linkages between insurance and climate-smart investment, there remain knowledge gaps.

Conducted between 2011-2014, the project involved three types of insurance design: 1) unsubsidized weather-backed index insurance, 2) subsidized weather-backed index insurance, and 3) weather-backed index insurance bundled with loans (hereafter referred to as interlinked insurance).

EPIICA examined the impact of the three insurance products on agricultural input, yield, and income. In a randomized experiment, neither unsubsidized insurance nor subsidized insurance led to a significant change in these three factors. Promisingly, a difference-in-difference study showed that farmers with interlinked loans demonstrated an increase in fertilizer use (Ahmed, et al., 2019).[1] The potential of interlinked loans to increase investment highlights the importance of credit access. We posit that the positive effect of interlinked insurance is not limited to synthetic fertilizer; the positive effect likely extends to more climate-friendly technologies as well.

Further analysis is needed to determine the impact of index-based insurance in other contexts. Ahmed, et al. (2019) was carried out in locations characterized by 1) exposure to droughts and considerable weather variation, 2) heavy reliance on rainfed agriculture, and 3) relatively low utilization of improved seed varieties and chemical fertilizer. The unique conditions under which the project was carried out may limit the external validity of the study results, and it may be incorrect to generalize the study's findings to other contexts. The risk model framework detailed in Chapter 3 seeks to provide clarity on the relationship between insurance and investment in other contexts.

We examine the case from the lens of the aforementioned switch factors: 1) weather and basis risk, 2) technology's cost, profitability, and embedded protection, and 3) risk exposure and loss.

[1] It is important to note that the difference-in-difference study was subject to notable limitations, and the authors warn that its results should be interpreted with caution.

2.2.1 Weather and Basis Risk

Climate change is expected to increase the unpredictability of seasonal and interannual climate variation, leading to the increased frequency and severity of extreme weather events. Amhara State is characterized by high levels of rainfall variability (Ayalew, et al., 2012). Increased climate variability will lead to a corresponding decrease in yields and increase in production risk. Climate impacts on weather variability are also localized to some extent, which may increase basis risk.

However, EPIICA does not explore weather and basis risk in-depth. Ahmed, et al. (2019) does not examine how climate impacts will affect the ability of insurance to promote investment. The question remains as to how variation in weather and basis risk will affect insurance's ability to de-risk investments in the face of the uncertainty around a changing climate. Climate impacts may become so severe that farmers may need to utilize a combination of tools in order to mitigate risk. The risk model framework serves to facilitate understanding of the conditions under which insurance is indeed beneficial.

2.2.2 Technology

EPIICA shows that Interlinked insurance demonstrates potential for increasing inputs, yields, and incomes. In a difference-and-difference study conducted in one village, interlinked insurance resulted in an increase in agricultural inputs and productivity over the study period. Two-thirds of farmers that possessed interlinked insurance reported an increase in chemical fertilizer use (Ahmed, et al., 2019).

On the other hand, the case study illustrates that cost considerations are important to increasing investment. A randomized experiment showed that neither unsubsidized insurance nor subsidized insurance without access to credit led to a significant change in agricultural inputs, yields, or incomes (Ahmed, et al., 2019), highlighting the importance of providing credit access to increase investment.

Access to agricultural and technological inputs was constrained by some form of cost considerations for nearly half of participating farmers. EPIICA classified the sample of farmers into four categories: unconstrained, quantity rationed, price rationed, and risk rationed. A little more than half (54.6 percent) utilized credit to leverage productive investments. The remainder (45.4 percent) were constrained by some sort of cost considerations, including lack of credit access.

Constraints	Definitions	Percentage of Sample
Unconstrained	Currently using credit	54.6%
Quantity rationed	Would not be able to access credit	18.8%
Price rationed	Could get loan but find it too expensive	6.8%
Risk rationed	Could get loan, and would be able to cover interest costs on average, but unwilling to bear the risk of possible default	19.8%

Table 1: Constraint Categories

EPIICA provides limited insight into how a technology's embedded protection to climate risks influences the benefit of insurance. The project involves synthetic fertilizer, which is not considered climate-smart due to the fossil fuels required in the production process. We posit that the positive effect of interlinked insurance is not limited to synthetic fertilizer, but likely extends to more climate-friendly productive investments as well. Climate-smart technologies vary in terms of their ability to protect against climate risk: some offer more protection, while some offer less. Insurance's benefit to the farmer decreases as the technology's protection increases.

The case demonstrates that the ultimate value of insurance to farmers rests on three aspects of technology: cost, profitability, and embedded protection. Access to credit is also important for enabling technological access. The model sheds light on how these factors interact with each other to influence the conditions under which insurance brings about a positive net benefit to farmers, which we will examine in further detail in Chapter 3.

2.2.3 Risk Exposure and Loss

EPIICA illustrates that risk exposure is a significant factor influencing the ultimate value of insurance to farmers. As depicted in Table 2.2, while 81 percent of surveyed farmers have credit access, only 67 percent of those with credit access currently take out loans. The remaining one-third of those with credit access choose not to due to concerns about risk exposure, with farmers fearing the cost and default risk of taking out loans.

EPIICA also points to the importance of insurance design in addressing risk exposure. We suggest that risk exposure was a key driver to the failure of farmers who received insurance without access to loans to increase agricultural investment. Interlinked insurance has the potential to unlock substantial credit demand by reducing risk-related obstacles to investment (Ahmed, et al., 2019).

Further analysis is needed in order to determine how variation in risk exposure affects the ability of insurance to promote climate-smart investment. The model elucidates the conditions under which insurance brings about a positive net benefit to farmers at any given level of risk exposure, which we will examine in further detail in the next section.

3. Risk Model Framework

3.1 Aim of the Model

From our research, we have seen that there is little or no study done on how index insurance can help increase the productivity and resilience of the farm. In short, does investing in index insurance lead to an increase in CSA investment, and if so, how and when? The gap in the knowledge is from the fact that there might be a few factors that affect a farmer's decisions (switch factors), but the interaction, and the extent of it is unknown. And that's where the model fits in.

The aim of the model is to evaluate different scenarios whereby investing in productive assets including CSA and non-CSA tools and practices can be beneficial to the farmer. Extending this argument, the model aims to deconstruct various scenarios in which purchasing insurance is a viable option for smallholder farmers to mitigate climate risk and purchase climate smart agriculture.

As mentioned earlier, It is important to note that in the model, CSA has three aims: higher productivity, higher resilience, and lower pollution. Hence, CSA can refer to a spectrum of investments: from productive investments, like high-quality seeds, adequate fertilizer, and irrigation measures like furrow irrigation, to CSA investments like drought-resistant seeds, drip irrigation technology,

3.2 Model Setup

The model has five inbuilt scenarios that aim to capture the decisions farmers have to make to increase their productive investment, and the tradeoffs involved with doing so. Similar to Chapter 1, these scenarios are explained like the decisions that a farmer must take as she decides what is the best way to safeguard her farm against weather risk, and increase profitability while managing the costs. Apart from the five scenarios, the model considers our set of three decisive factors - switch factors - which alter the potential of index-based insurance to de-risk productive investments in CSA and safeguard the farmer in the case of weather disasters.

3.2.1 Representation of Switch Factors

Switching factors, as described in Chapter 1, are exogenous factors that determine whether insurance becomes a catalyst to foster CSA investment, and under what conditions. These switch factors are measured in different ways inherently in the model. These switching points influence when and why the farmer takes the decision to move from one stage to another.

3.2.1.1 Weather and Basis Risk

The weather refers to the incidence of weather-related disasters that affect the farmer's yield and revenues. Let's take the example of the R4 Rural Resilience Initiative. In the regions this project was conducted, farmers relied heavily on rain-fed agriculture and were faced with a growing risk of droughts as rain patterns were erratic. In addition, these three regions also suffer from higher poverty rates than Senegal's national average, which amplifies the adverse effects of frequent and severe climate shocks on farming communities.

This report analyzes the frequency and severity of weather-related shocks portrayed as less rainfall, and higher loss from this event.

- Severity: The severity is measured as the percentage loss of crop output due to a weather disaster. The farmer is creating a risk mitigation strategy that allows her to be safeguarded in the case of a drought, flood, etc.

- Probability of a bad year: This measures how often a bad year occurs, as a percentage. For example, if the probability of a bad year is 20%, a bad year occurs once every 5 years. Conversely, this also means that 4 out of the 5 years are good years, or 80% is the probability of a good year.

Basis risk is the imperfection in the insurance. Basis risk refers to the mismatch between the weather index and the actual loss of a farmer. When combined with other factors, such as lack of trust in the insurance provider, limited liquidity, and lack of familiarity with the insurance principles, the demand for index-based insurance can be limited, and affect that farmer's decision to invest. The R4 project actively recognized this problem of basis risk, and its effect on farmers' willingness to purchase insurance.

In the model, we call this the payout probability in a bad year. Insurance is effective when the insurer's bad year and the farmer's bad year coincide, whereby the insurance payout covers the farmer's losses in the right year. So, a payout probability measures this coincidence.

- Insurance cost: The insurance cost is calculated as a premium rate multiplied by the expected revenue/output. In this multi-step calculation, the premium rate is arrived at by multiplying a few factors: the probability of a bad year, loading factor, average loss percentage. Note that the expected revenue which is covered by the Insurance is calculated by simply multiplying the average yield by the average price in each scenario.

  - Loading Factor: The loading factor is described as the amount that: covers the operating cost of the insurer; chance that the insurer's losses for that period will be higher than anticipated, and the changes in the interest earned from the insurer's investments. This is added to the amount required to cover losses, known as the pure insurance cost. It is measured as a percentage of the insurance cost itself. In the model, the loading factor is included in the cost as (1+ loading percentage). Loading percentage is one of the dynamic input assumptions in the model. For example: loading percentage of 15% means a loading factor of 1.15 on the insurance cost.
  - Average loss percentage: Average loss percentage is taken as we assume index insurance bases its premium calculation on the average loss percentage for the area covered by Index Insurance.
  - Optional Insurance Cost Subsidy: The government can provide a subsidy to reduce the cost of insurance to the farmer. This subsidy is provided with the aim of increasing the uptake of insurance. This subsidy is measured as a percentage as a reduction on the total insurance cost and can range from 0% to 100%.

- Insurance payouts: The payouts from the insurance, if taken, are supposed to happen in the bad year. But due to basis risk, the payouts do not happen in all bad years. This basis risk is captured through the factor ‘Payout Probability in a bad year’. For the bad years where payout occurs, payouts are calculated as payout coverage multiplied by the expected revenue.
  - Payout Probability in a bad year: This measures how often the insurance pays out in the coverage period. In the case of index insurance, weather data triggers a payout. An insurance is effective when the insurance bad year and the farmer’s bad year coincide, whereby the insurance payout covers the farmer’s losses in the right year. So, a payout probability measures this coincidence. It is measured as a percentage. This captures the Basis risk of insurance as (1- Payout Probability in a bad year).
  - Payout Coverage: The payout coverage is pre-decided at the time of signing the insurance contract. It’s calculated as a percentage of the average yield multiplied by the average price (per MT) that the insurance covers. For example, a 50% payout coverage means that the insurance pays the farmer 50% of his average earnings from that field. Since this is an index insurance,

the payout coverage is the same for every scenario, independent of the severity of the weather risk.

3.2.1.2 Technology

This factor refers holistically to the new technology that the farmer invests in. The factors connected to it are: increased cost, increased profitability, and increased embedded protection. Investing in any technology comes with increased cost and potential borrowings for the farmer. But this is balanced by the increased yield, profitability, and the embedded protection that these investments provide.

Let's take the example of the EPIICA. It examined the conditions under which insurance promoted agriculture investment among drought-exposed farmers in Ethiopian villages. In terms of technology, the study found that access to technology was constrained by cost considerations, and a little more than half of the participating farmers needed to utilize credit to leverage productive investments, whereas the remainder couldn't purchase. Hence, cost acts as barrier to technology, which in turn affects the profitability and risk protection

Through this lens, it is important to find the right overall cost-yield relationship and the decreased exposure to climate risk, to assess the benefit of technology from a farmer's perspective.

The cost is the amount the farmer has to spend (or borrow) to invest in CSA equipment. This is measured in the model as the increasing production costs in each scenario.

- Production Costs: The farmer has to bear an upfront cost in each farming cycle - this covers the various inputs like seeds, fertilizers, manpower, etc. The cost varies depending on the farmer's investments in CSA and non-CSA investments (like irrigation, high-quality fertilizer, etc.). It is assumed that for every upgrade the farmer invests, the costs per annum increase.

- Optional Production Cost Subsidy: This is a subsidy provided by the government to reduce the production costs incurred by the farmer. The subsidy is calculated as a percentage of the production cost that is covered and can range from 0% (no subsidy) to 100% (full subsidy). Subsidies are awarded on Non-CSA productive investments and CSA investments to increase their uptake by farmers.

- Savings and Borrowings: The model assumes that the farmer has no initial savings to invest in the farming cycle. She borrows to cover all expenses - production expenses, investments in CSA, and insurance - with an interest rate on the borrowings. If the analysis needs to be extended to account for the impact of using savings for agricultural investments, there are two dynamic inputs already built into the model i.e. Initial savings and percentage of savings used for agricultural investments. In case only a proportion of available savings are used for investments, the remaining savings will then serve to mitigate any risks due to shortfall of revenue in covering the interest costs, basic necessities like food, etc.

The profitability is the initial benefit and expected benefit the farmer makes in each scenario, after taking into account the production costs, borrowing costs, insurance costs, insurance payout (if any), and penalty (if any). Specifically, with technology, the increased yield in each decision, post-investment, showcases the increased profitability in relation to the technology.

- Yield: The yield differs based on the farmer's investments in production investments and CSA. Without any productive investments (no high-quality seeds, no fertilizer, fully rainfed), the yield is the lowest (the base case), and the yield increases as we increase the productive investments. This is because of the two factors: one, with each upgrade, the yield increases the productivity of the land; and secondly, the embedded protection factor of the productive investments also comes into effect through the severity of the weather disaster. The yield is measured in yield metric ton (MT) per hectare (ha).

- Initial expected benefit: This is calculated as a simple revenue minus cost to ascertain if the farmer made a profit in the year. The costs here include the production costs, borrowing costs and insurance costs, if applicable, and the revenue is the yield from the farm plus insurance payouts, if applicable. If the initial benefit is positive, it means the farmer's revenues are greater than the cost, and that she made a profit. If the initial benefit is negative, it means the farmer's cost is greater than the revenues and she made a loss. In this case, the penalty kicks in.

The embedded protection of the farm showcases how well it can withstand a bad year, with or without CSA investments. Hence, embedded protection is measured as the severity of a bad year. Overall, embedded protection and severity are negatively related.

3.2.1.3 Risk Exposure and Loss

Risk exposure is an inherent variable that the farmer deals with - it determines if, and how much she invests in technology and insurance, or a combination of both. Risk exposure is measured as the cost of financial loss, including the possibility of hunger, bankruptcy, loss of life, and further substantial harm.

Both studies look at risk exposure as an aspect that hinders a farmer's willingness to invest, but both studies point out the need for further analysis to determine the level of risk exposure that enhances investment in CSA.

The risk exposure in the model is measured through the penalty, or the risk of going negative. The higher the penalty percentage, the more risk-exposed the farmer is as this will take away from her ability to invest in other things such as education, food etc.

- Penalty: The penalty kicks in if the farmer's benefit, including left-aside savings and insurance payouts if any in a scenario, is negative. The rationale is that the farmer has borrowings that cover his production costs and must pay this back from the benefit (profit) made from the farm. But if the benefit is negative, she will need to borrow another loan to pay off the first one, thereby further reducing the benefit. The penalty is measured as the percentage of the net loss for going negative. For example, if the farmer incurs a ($100) benefit, and penalty for incurring a negative benefit is 100%, the farmer needs to borrow $100, thereby making the net benefit ($200). The penalty can range from 0% to any percentage based on the risk exposure of the farmer in the specific scenario. For the sake of simplification, the assumption of a penalty being levied is taken when the net benefit is below zero (negative), in the real world there could be penalties for not being able to earn a certain level of positive net benefit.

- Expected benefit: This is the final probability weighted net benefit that the farmer makes after taking into account initial benefit along with left-aside savings, insurance payouts and the penalty if any. The expected benefit is calculated based on the probability of each sub-scenario (Good Year & Bad Year) occurring, to explain the spread of the profit or loss. After adding the penalty and the insurance payout to the initial benefit, the new figure is multiplied by the probability of the sub-scenario, to arrive at the final expected benefit. In case of investments without insurance, the sub-scenario probabilities are that of a good year and bad year. In case of investments with insurance, the sub-scenario probabilities are that of a good year, bad year without payout and bad year with payout.

3.3 Decision-Making Framework

Now let's break down these factors and how they play into the model's scenarios. Each scenario builds on the previous and adds a layer of complexity. The aim is to find the scenario whereby insurance is profitable for the farmer. Each scenario is composed of two or three sub-scenarios: a good year, a bad year, and, in the case of insurance, a bad year with payout (Figure 3.1). We will describe the scenarios through the decision tree mentioned earlier. The switch factors help us determine when and how the farmer moves from one stage to another, and under what circumstances.

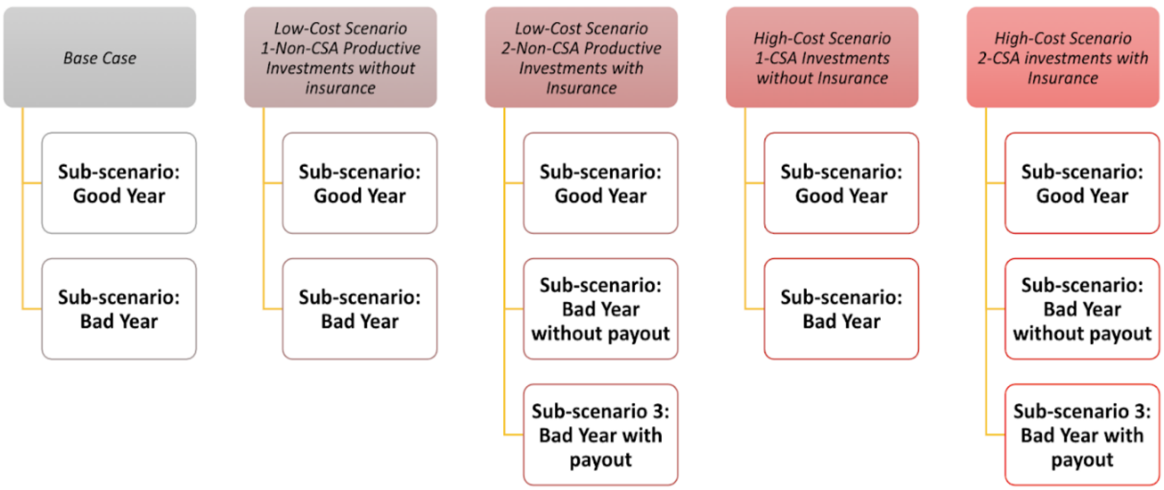

Figure 3.1: Scenarios Framework

The switch factors help us trace when farmers move from one stage to another, and what causes the switch to occur. The interaction of the factors is important as it can help policy-makers understand how they affect that farmer's investing decisions, and what motivates her to invest in different technology, at what point.

The base case is when the farmer invests in no-CSA technology and carries on business as usual. Let's assume a weather disaster occurs. The frequency and severity of it will push a farmer to think through various risk management strategies that can safeguard her farm. Based on factors like: cost of the technologies, potential profitability, added resilience, insurance design, and the overall risk aversion of the farmer, she may choose either a low-cost technology like furrow irrigation with no insurance, or go all the way to purchase high-end drip irrigation technology with insurance. There are various possibilities along the way, and how the farmer decides the perfect one for her is determined through the interaction of a few factors. This is discussed below. For a more detailed understanding of the various scenarios, please refer to appendix 8.1.

3.4 Assessing the key interactions using risk framework

This section briefly discusses how the key findings are arrived at from the one-year simplified risk framework. As discussed in the previous section, this risk framework simulates a farmers decision making process for various investment options with a set of stylized inputs based on approximated costs and prices for a smallholder farmer in Senegal. The risk framework formulation and findings were further complemented by the two case studies: R4 Project in Senegal and EPIICA (Ethiopian Project on Interlinking Insurance with Credit in Agriculture) that were discussed in an earlier section of the paper.

The framework consists of 5 different scenarios starting from base scenario i.e. rainfed agriculture to a less climate smart technology (without & with insurance) to more climate smart technology (without & with insurance). The two technologies (Less climate smart and more climate smart as mentioned earlier) used for illustration in the risk framework are Furrow irrigation and Drip irrigation.[2] These technologies are beyond the typical investments in R4 and have been discussed more from future context and usefulness. Drip irrigation was chosen as the CSA technology of relevance for Senegal as it was observed in the Senegal case study that the focus regions of the R4 project in Senegal - are characterized by their heavy reliance on rain-fed agriculture and farmers face a growing risk of droughts due to climate change. Therefore, these technologies though challenging may be helpful to adopt in this context. We combine these technologies with appropriate inputs such as high quality seeds, chemical fertilizers etc.The decision tree framework in the appendix under section 8.2 may also help in understanding a farmer's investment process and her switches across the path.

Using this framework, firstly the switching points are arrived at, where a farmer moves from one investment option to another.[3] For the purpose of analyzing the shift from one investment option to another investment option, the inputs for one or more dynamic factors are changed while retaining others at the preliminary input level (Ceteris Paribus condition, as defined in the appendix under section 8.3). At these switching points, identification of the most sensitive inputs using the sensitivity analysis is done that are called as "Switch Factors". Lastly, the key interactions of these switch factors are assessed that may impact adoption of CSA and usefulness of Index Insurance in such adoptions. Therefore, this simplified risk framework provides policymakers a tool which

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[2] Drip irrigation is the more climate smart technology that increases agricultural productivity, adaptation and resilience to climate change and reduce the impacts of agriculture on the environment by saving considerable water resources, while Furrow irrigation is a less climate smart technology that increases productivity and provides some resilience compared to rain-fed agriculture but does not lead to environmental friendly outcomes of conserving water resources.

[3] The shift or switch from the first to the second investment option is defined as the approximate point where the net expected benefit from the second investment option is higher than the net expected benefit from the first investment option. This approximate point is based on the set of dynamic input assumptions taken.

can certainly be expanded upon based on availability of data and can help assess factors and interactions affecting the switches across the investment options by the farmers and how insurance affects these switches.

The sensitivity analysis illustrates the policy bandwidth that a stakeholder has under various conditions at which index-based insurance enhances investments in productive assets and specifically in CSA techniques.

A brief overview of some of these factors motivating or inhibiting the specific shifts or switches under stated input conditions across investment options as observed is presented here.[4]

3.4.1 No Insurance Case

Which factors promote switching from non-CSA or less climate smart technology Investment options to more climate smart technology Investment options if there were no insurance?

We analyse this case to assess what are the basic factors that motivate the switch towards resilient CSA technologies in the absence of risk transfer mechanisms such as insurance.

Non-CSA or Less climate smart technology without insurance to more climate smart technology without insurance:

Although the switch from less climate smart technology without insurance to more climate smart technology without insurance will be driven to a great extent by the differential costs, yields and embedded protection levels of the two technologies, the probability of a bad year and interest rate of borrowing also play an important role.

For the switch from non-CSA (base case scenario of rainfed agriculture) to CSA (less or more climate smart), the climate risk represented here by the probability of a bad year is again one of the major driving factors. The increase in the probability of a bad year may increase the attractiveness of the more climate smart technology option over the less climate smart technology due to high yield and high embedded protection benefits associated with more climate smart technology. It was observed that an increase in the probability of a bad year to 40% renders the less climate smart option unviable, thereby increasing the attractiveness of the more climate smart technology investment option. But considering the positive externalities from climate smart investments, policymakers may find it beneficial to support the farmers' transition to CSA technologies even at lower levels

[4]In the following sections, the less climate smart technology refers to furrow irrigation and more climate smart technology refers to drip irrigation as the analysis is based on numbers specific to these technologies. And the insurance refers to weather index insurance.

of climate risk. And considering the productivity benefits of the CSA, this may just require some support in the form of technology subsidies etc. so as to overcome the initial investment barriers due to risk exposure .

This switch from the less climate smart technology without insurance to more climate smart technology without insurance may also be heavily dependent on availability of borrowings and borrowing costs (interest rates). Ceteris paribus, given the high yield and higher embedded protection level of the more climate smart technology option, higher interest rates up to a certain level are affordable in the more climate smart technology option as compared to the less climate smart technology option. It was observed that as interest rates increase from 15% to 35%, the attractiveness of the more climate smart technology option increased as compared to the less climate smart technology option, and for interest rates beyond 35%, even more climate smart technology option became unaffordable.

Therefore, increasing the probability of a bad year and availability of borrowings at affordable interest rates can promote switching to more climate smart technology investments apart from the underlying characteristics of the CSA technologies.

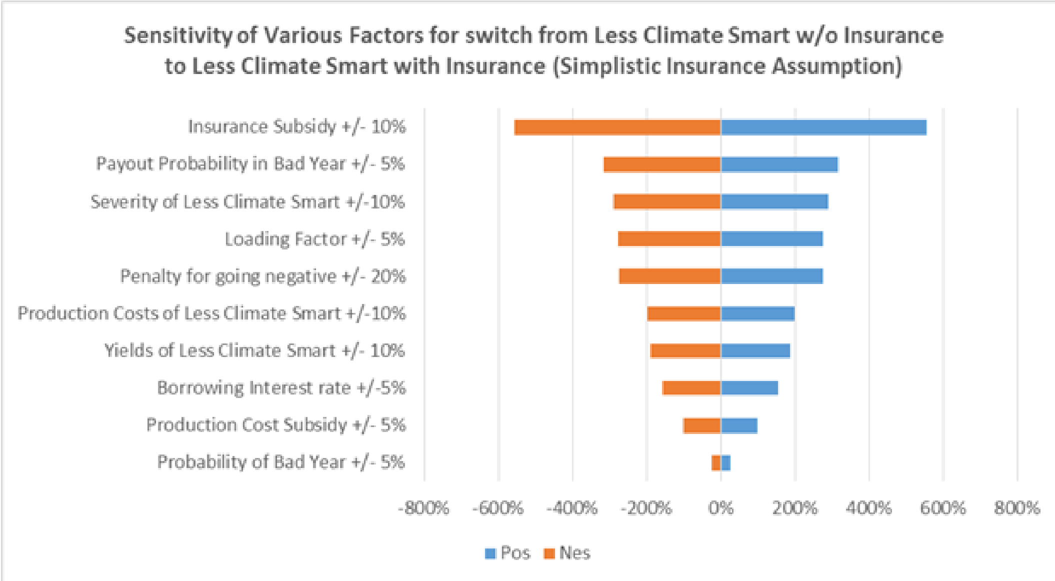
3.4.2 Simplistic Insurance Case

Which factors promote switching from non-CSA or less climate smart technology options to more climate smart technology options under the assumption of a simplistic insurance (no basis risk and actuarially fair insurance)?

For this case, we assume a simplistic insurance option i.e. insurance cost without any loading (0%), no basis risk (100% payout probability in a bad year), and full loss coverage (100% insurance coverage and 100% loss percentage taken for cost calculation also). The usefulness of this form of insurance can be used as motivation for the community savings and insurance programs under the given conditions as these programs may exhibit no loading and minimal basis risk.

Less climate smart technology without insurance to less climate smart technology with insurance:

In the less climate smart technology scenario with the cost-yield assumption, the penalty threshold that encourages the switch from no insurance strategy to with insurance strategy may be as low as 60% penalty at full cost (or 0% subsidy).



Graph 3.5.1: Sensitivity of various factors for switch from less climate smart technology without insurance to less climate smart technology with insurance under simplistic insurance assumption

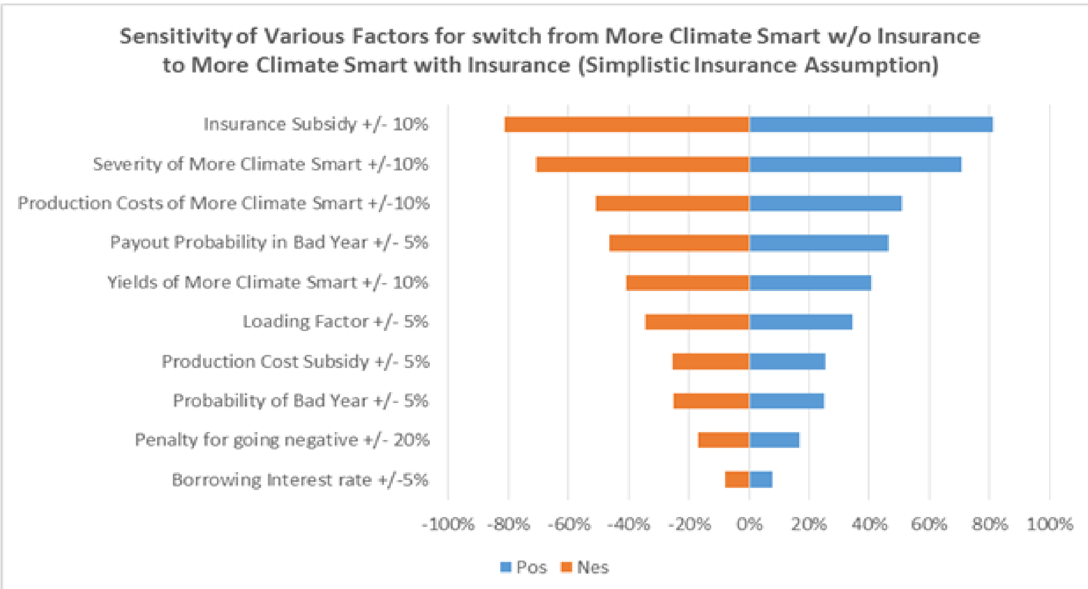
At 60% penalty, other factors to which this switch may be more sensitive include insurance subsidy, basis risk (payout probability), the embedded protection level of the less climate smart technology scenario, and loading factor. For instance, if the embedded protection of the less climate smart technology investment scenario is lower (80% severity) instead of the standard assumption (60% severity), then the switch from a no-insurance to insurance may occur at a lower penalty of 35%.

More climate smart technology without insurance to more climate smart technology with insurance:

In the more climate smart technology Investment scenario, penalty switch factor may not be that effective as the high yield and high embedded protection may be taking over as more significant factors leading to higher expected benefits even without insurance. Due to the high embedded protection of more climate smart technology, the residual risk left to be covered by insurance is limited.

The insurance option is also not effective as the insurance cost increases under the more climate smart technology scenario because of increased coverage of the higher expected yield. Under these circumstances, lowering insurance costs with a subsidy of 15-20% increases the net-expected benefit of a more climate smart technology with insurance compared to a more climate smart technology without an insurance strategy. Nevertheless, it was observed that the benefit in good years was extremely low under the with-insurance-strategy due to the high cost of insurance.

To estimate how sensible this shift is considering the insurance subsidy requirement, we compare the benefit in good years, with and without insurance. The findings indicate that even with an insurance subsidy of 40%, the good year benefit with an insurance scheme is still half of the benefit without insurance. This indicated that the costs need to be lower for the index-insurance to unfold its de-risking potential which may not be effective. One way to reduce the insurance cost would be to take into account only the residual risk of the individual farmer based on the embedded protection of the underlying agricultural technology used.



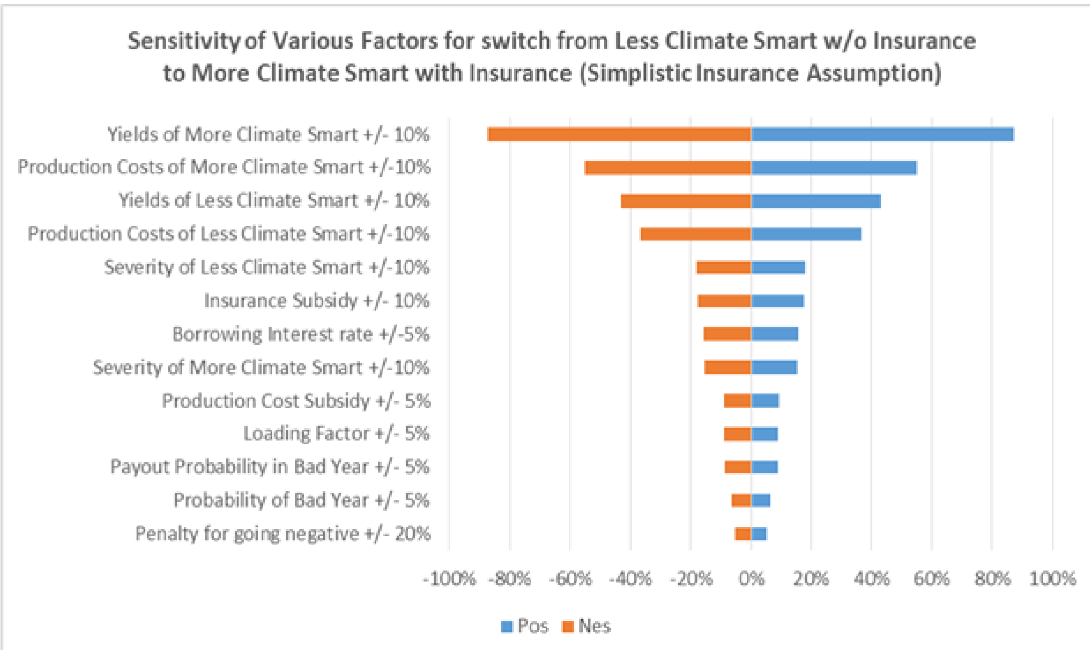
Graph 3.5.2: Sensitivity of various factors for switch from more climate smart technology without insurance to more climate smart technology with insurance under simplistic insurance assumption

At this level of insurance cost, it can be observed that embedded protection of the underlying technology alters the switch. While the insurance may not be beneficial in the option with more embedded protection (severity of loss 20%), it may be beneficial in a scenario with less embedded protection (severity of loss 40%). This indicates that the combination of index-insurance and CSA is beneficial until a certain threshold of embedded protection where there is enough residual risk for the insurance to cover cost effectively. Apart from insurance subsidy and embedded protection, the switch is sensitive to the level of production costs and basis risk (payout probability).

Less climate smart technology without Insurance to more climate smart technology with Insurance:

The most significant factors that drive switching between these two options are the differential characteristics of the two technologies i.e. the level of the yield, production cost, and embedded protection levels of the two technologies.

We observed that lowering interest rates for borrowing or reducing the cost of production, e.g. by introducing a subsidy can have significant effects. Although with the preliminary set of inputs also, the net expected benefit of more climate smart technology with insurance scenario may be higher than that of the less climate smart technology without insurance but the good year's outcomes are extremely low for more climate smart technology with insurance strategy due to high insurance costs. Therefore, the switch may not be effective under certain levels of climate risk.



Graph 3.5.3: Sensitivity of various factors for switch from less climate smart technology without insurance to more climate smart technology with insurance under simplistic insurance assumption

Even with the insurance subsidy of 60% or more, the benefit of having insurance with more climate smart technology is lower than more climate smart technology without insurance. This might be explained by the increase in embedded protection by using more climate smart technology (20% severity of loss) and therefore limiting the utility of high cost & high coverage insurance.

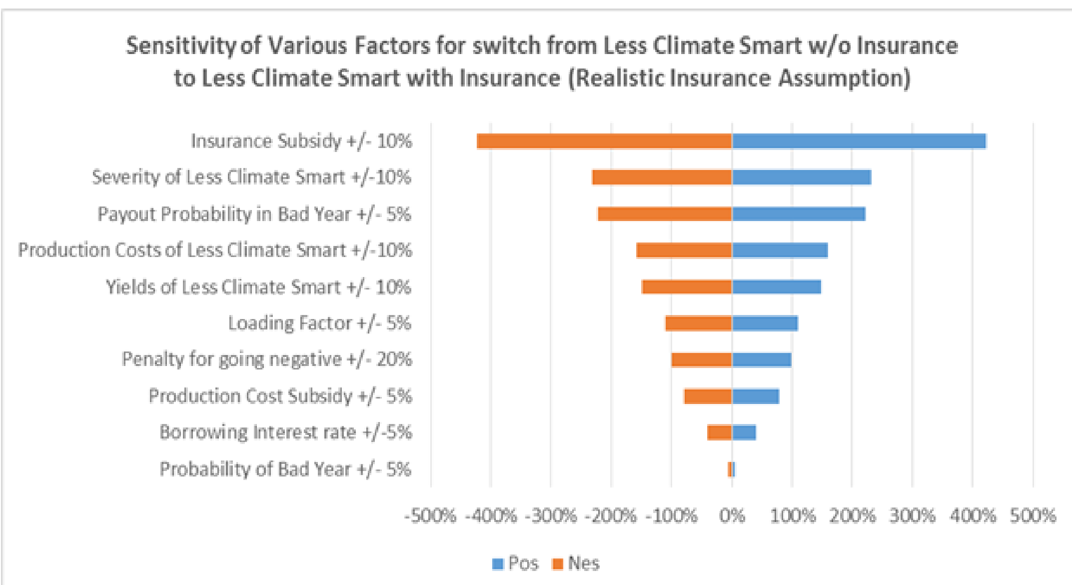
3.4.3 Realistic Insurance Case

Which factors promote switching from non-CSA or less climate smart technology to more climate smart technology when the realistic insurance is available (when loading, basis risk, and partial coverage are present)?

This case better reflects the real-world insurance with 15% loading, a payout probability of 66% and a basis risk of 33%. Further the scenario accounts for an average loss percentage for the insurance cost calculation at 85% and factors in an insurance payout coverage at 85%. This case helps us in assessing the interactions of the underlying technology, basis risk and insurance usefulness under various conditions.

Less climate smart technology without insurance to Less climate smart technology with insurance:

One major change to note here as compared to the simplistic insurance case is that the increased cost (loading factor) and reduced benefit from insurance (basis risk: bad years without payouts and less than 100% payout coverage even in the year with payout). Therefore, the switch from non-insurance to insurance scenario is difficult without appropriate insurance subsidy. Furthermore, compared to the simplistic insurance case, the penalty factor has reduced importance in driving the shift from the non-insurance to the insurance scenario. The reasons may be the above mentioned higher costs and the reduced benefit of insurance.



Graph 3.5.4: Sensitivity of various factors for switch from less climate smart technology without insurance to less climate smart technology with insurance under realistic insurance assumption

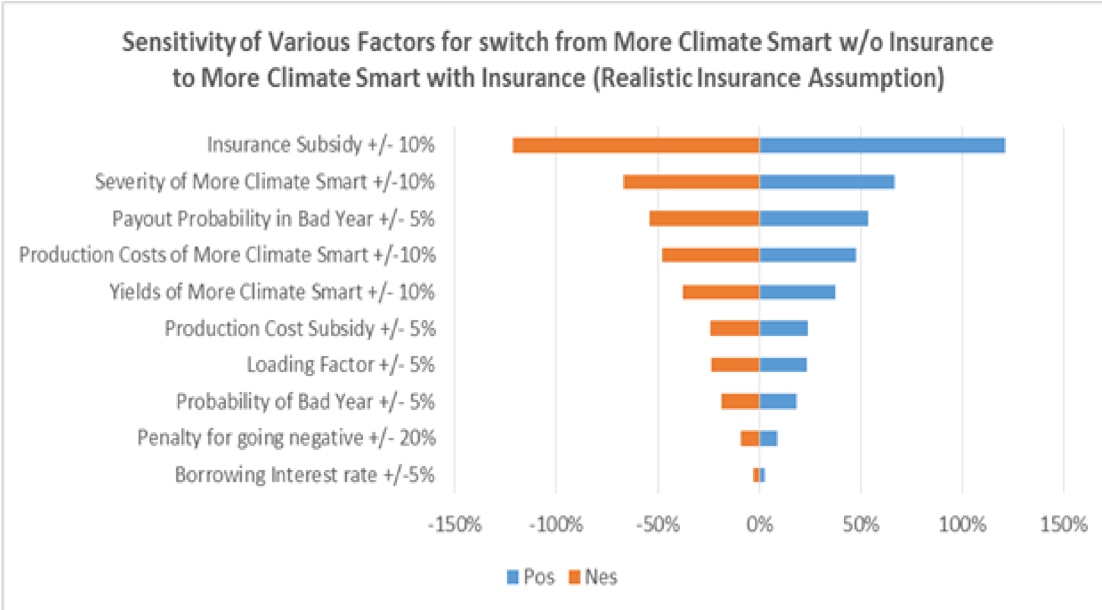
For the given set of cost-yield combination for less climate smart technology, one way to make this switch may be to use around 40% insurance subsidy at the severity of loss level of 60%; the required insurance subsidy may dip to 30% if the severity of loss level for the investment option is around 80%. Other factors that may drive this switch is a reduction in basis risk (increasing payout probability in a bad year) and reduced production cost for this yield or higher yield at these production costs. For instance, if the basis risk is reduced from 33% to 20%, then 25% insurance subsidy may be enough (instead of 40% insurance subsidy). Therefore, investing in well designed insurance policies to reduce basis risk might be a more effective alternative to consider.

More climate smart technology without insurance to more climate smart technology with insurance:

In comparison to the simplistic insurance case, here the minimum amount of insurance subsidy required to make the switch from no-insurance to insurance option is higher. In this case, we have found that level to be around 55%. However, the net benefit of purchasing insurance is only marginally higher. Therefore, again pointing to the fact that investing in data collection and well-designed insurance policies to reduce basis risk might be a more effective alternative.

Furthermore, the switching factor is highly driven by the underlying technology i.e. embedded protection potential of the more climate smart technology investment. For instance, if the severity of the loss is increased from 20% to 40% the risk exposure (penalty) factor may help drive the switch to the insurance option. Further, at a lower level of embedded protection, the penalty does not drive the switch by itself. This finding leads to the conclusion that an insurance subsidy and risk exposure (penalty) together might cause the shift to the insurance scenario to become more beneficial under increased frequencies of bad years (upto a certain level).

Therefore, at high embedded protection (20% severity of loss) of more climate smart technology investments, the switch to the insurance option may not be optimal even with a high insurance subsidy (>55%). In fact, in this case the farmer might be better off saving a portion of the earnings from a good year to cope with the losses in the bad year. And, the policymakers might be better off investing in improving the insurance design.



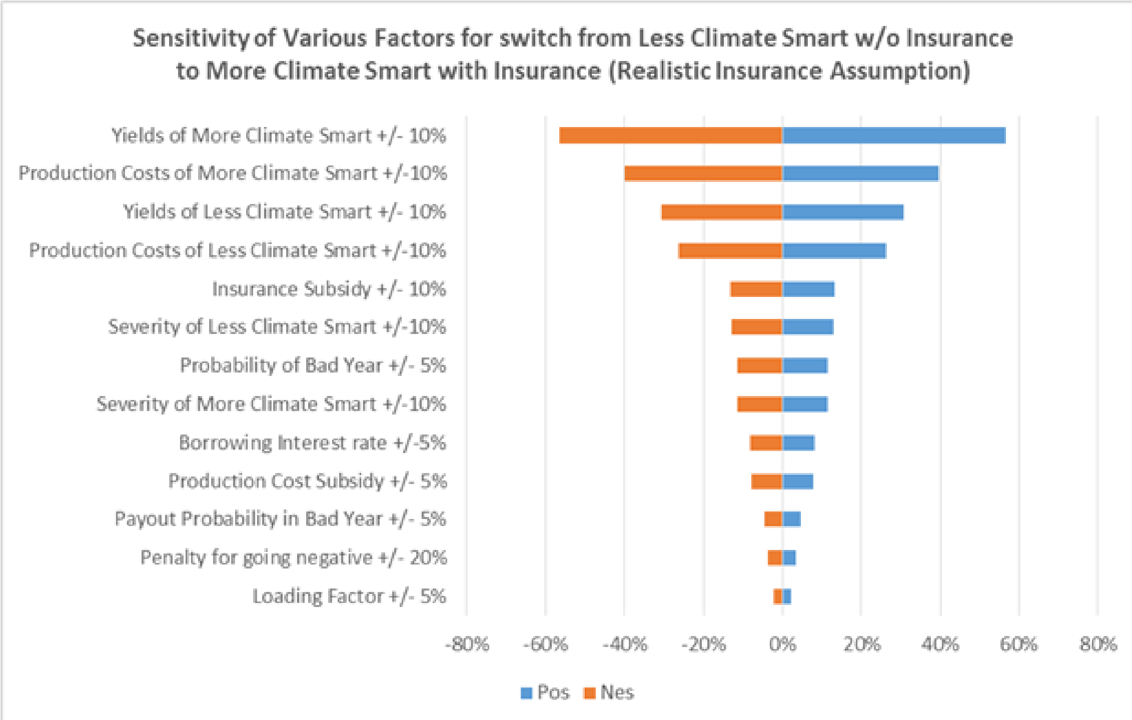
Graph 3.5.5: Sensitivity of various factors for switch from more climate smart technology without insurance to more climate smart technology with insurance under realistic insurance assumption

In conclusion, we have identified that index insurance can promote investments in more climate smart technology at an appropriate level of insurance subsidy to cover the residual risk when the technology becomes overwhelmed due to increased climate risk. Further, basis risk and the cost-yield combination of the more climate smart technology also significantly alter the switch.

Less climate smart technology without Insurance to more climate smart technology with Insurance:

Similar to the simplistic insurance case, in this case also the cost-yield-embedded protection combination of the agricultural technology promoted the switch from less climate smart technology without insurance to more climate smart technology with insurance. Further in this case, the increased climate risk reflected in an increased probability of a bad year is another sensitive altering factor for the switch.

It is observed that a minimum of a 60% insurance subsidy may be required to encourage the switch from the less climate smart technology without insurance to the more climate smart technology with an insurance strategy (with the more climate smart technology's severity of loss at 40%).



Graph 3.5.6: Sensitivity of various factors for switch from less climate smart technology without insurance to more climate smart technology with insurance under realistic insurance assumption

But if the more climate smart technology's severity of losses is at 20% (higher embedded protection) then with a 60% insurance subsidy, the switch to more climate smart technology with an insurance scenario may not be optimal as the farmer was already earning better outcomes in case of more climate smart technology without an insurance scenario.

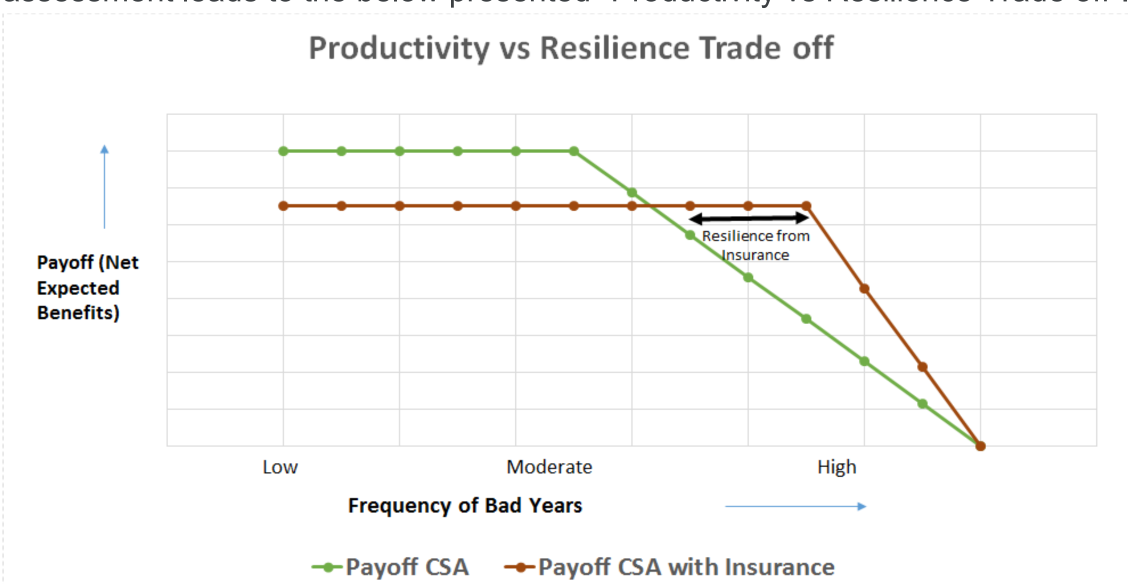
We again concluded that the index insurance may promote investments in CSA if the frequency of bad year (less rainfall in this case) becomes so high that the farmer may not be left with enough water resources even for the drip irrigation (CSA) technology (low water consuming technology). In this case, insurance will be useful to cover residual risks as technology becomes overwhelmed due to high climate risk.

4. Applicability of the Framework

This paper aims to provide a broad framework in the form of a simplified one-year model for illustrating how the various factors encourage or inhibit the switch from the base scenario to more risky productive investment scenarios. These risky investments can be short term high productivity driven investments (Non-CSA) or short-term CSA-driven investments or long-term CSA-driven investments. The presented single year model is agnostic on the type of investment (CSA vs non-CSA productive/risky investment). This renders its usefulness in the evaluation of all alternatives by changing the dependent numbers of the underlying technology such as costs, yields, resilience (severity of loss in case of climate disaster) etc. These input numbers may not be linear, for example one may have to also account for sub-components like cost savings resulting from the CSA option if any. For instance, in case of drip irrigation there would be savings in fertilizer cost (on account of liquid fertilizer use) and labor cost (on account of reduction in physical irrigation & fertilizer application).

4.1 Key Findings

1. **The Nexus among Frequency of bad years, Technology and Insurance:**
   To assess the stage of usefulness of insurance along with CSA we observe the nexus among the three factors i.e. Frequency of bad years (Climate Risk), Technology (Cost-Yield-Embedded Protection combination) and Insurance. This assessment leads to the below presented "Productivity vs Resilience Trade off".



As we can observe in the above displayed Payoff graph[5], at low and upto moderate frequency of bad years, it probably makes sense for CSA technology and the farmer to uphold the risks themselves. At the lower levels of climate risk, productivity portion of the technology is the key driver and at moderate levels of climate risk, resilience portion of the technology is the key driver. As the frequency of bad years increases and we move to the point where the two lines intersect along the x-axis, it becomes beneficial to use insurance for covering the residual risk as a complementing measure. At the point of intersection, the technology starts becoming overwhelmed and therefore insurance can be useful to de-risk CSA investments. This nexus can be explained in terms of the Productivity-Resilience trade off. Reduced productivity in good years represents the cost of insurance and increased resilience beyond the point of intersection represents the benefits of insurance. Therefore, assessment of at what point or stage this productivity-resilience trade off for a particular technology is beneficial is important in understanding the usefulness of insurance to de-risk CSA investments. It is also important to note that the underlying technology is a major driving factor for such assessments. For instance, for a technology of lower resilience as compared to drip irrigation, the switching point may come at an earlier stage of climate risk.

2. **Risk Exposure, Technology (CSA) adoption and usefulness of Insurance:**

As we observed in the Senegal and Ethiopia case studies, poor smallholder farmers in developing countries are oftentimes constrained by several limitations that hinder their ability to go for high investment required for CSA technologies. For a farmer who is not exposed to risk, the self-sustaining benefits in terms of increased productivity and resilience can drive the technology adoption when there is credit availability. But risk exposure is a major factor inhibiting technology adoption. As discussed earlier, risk exposure is the cost of financial loss, including the possibility of hunger, bankruptcy due to inability to pay back a huge loan etc. In the risk framework, the same is observed through the proxy “Penalty factor”. Also in the case of Ethiopia, we noted that more than 25% of farmers could access credit but did not invest due to risk exposure.

We also observed that the increasing climate risk may render the non-CSA technology unviable after a certain level of climate risk (represented by frequency of bad years in the risk framework) and therefore may drive the CSA adoption organically if there is credit availability. The proactive technology adoption at lower levels of climate risk may however require initial transitioning support in terms of

[5] It may be useful to note that although the graph includes the increasing cost of insurance (due to high frequency of bad years), the same is not highlighted in the graph due to the corresponding increase in payout frequency. Also, low frequency very large tail events are not illustrated in the graph.

technology subsidies.

Specifically, at high levels of climate risk, insurance can promote CSA investments by covering the residual risks as the technology becomes overwhelmed. For instance in the case of Ethiopia, we observed that two-thirds of farmers that possessed credit interlinked insurance reported an increase in productive investment level. Also, in the case of Senegal, we observed that households with insurance spent more on average on agriculture inputs including productive investments than those without insurance.

It is also useful to note that at a very high level of climate risk, even insurance may not be useful and therefore investing in transitioning to other viable sources of income or in creating better technologies might be a better alternative.

3. Interactions affecting the Subsidy decisions:

One of the major dilemmas that policymakers often face is with regard to the subsidies as to where and when the subsidies would be more effective to provide. Ideally, if the investment in technology is self-sustainable and if the risk transfer through insurance is effective then no subsidies should be required. However while assessing the various factors in the risk framework, we observed that there are certain interactions that can guide the subsidy decisions to create right incentives for the various stakeholders in the system.

a) It was observed in the analysis through the risk framework that basis risk significantly alters the risk mitigation potential of index-based insurance. As basis risk increases, value of the insurance for the farmer decreases. And as we discussed earlier also, the major reasons for high basis risk include lack of sufficient data for large-scale agricultural insurance programs, low investments in new technology etc. (Boudreau, 2010)

   Compensating for basis risk through subsidies is expensive and not a good policy decision in terms of building right incentives for the stakeholders. Therefore, subsidies should not be provided for the badly designed insurance policies rather investing in improving the insurance design or funding public goods, such as weather information may be more effective alternatives.

b) It was also observed that due to high investment requirements, risk exposure can inhibit farmers from proactive adoption of CSA technologies. Therefore, by subsidizing a part of initial technology costs, proactive transition to high cost CSA technologies can be encouraged at low levels of climate risk.

c) Further, CSA technologies may have benefits in terms of reducing negative externalities such as pollution and carbon emissions or increasing positive externalities in terms of water conservation. Though our risk framework does not capture these additional benefits from externalities resulting from technology adoption, the same may be valid criteria for subsidizing technology cost as these benefits are not captured at the individual farmer level. For example: Considering the benefits of water conservation resulting from drip irrigation adoption, the government may find it beneficial to incentivise early adoption of this technology by providing subsidies.

d) Also as we discussed under the "Productivity-Resilience Trade off", at high levels of climate risk subsidizing insurance can be beneficial to cover the tail risk / residual risk which the underlying technology was not able to mitigate. However, it may be noted that after a certain point of increased climate risk even insurance may not be helpful and therefore would require a transition to other income sources or development of better technologies.

These approaches to subsidizing follow the overarching principle of building the right incentives for various stakeholders as against providing huge subsidies to promote uptake of a badly designed insurance policy.

4.2 Limitations

- Factors such as cost for holding money for emergencies/ bad years and opportunity cost of savings used for agriculture have not been considered in this simplified model. This broad framework can be extended to cover these complexities.
- For the purpose of this simplified model, it is assumed that the Index insurance premium rate is calculated as the probability of a bad year multiplied by the loading factor multiplied by the average loss percentage (for the region covered by Index), where the average loss percentage has been assumed to be the same level as insurance payout coverage. Therefore, this model can be extended to include more complex index insurance modeling by including all necessary factors and variations.

- The assumption of the penalty being levied in this model is taken when the net benefit is below zero (negative). In the real world there could be penalties even for not earning a certain level of positive net benefit.

- CSA productive investments usually involve a long-term investment with some sort of asset creation that has a long useful life. Therefore, NPV analysis is the better way of analyzing the cost-benefits of projects involving CSA investments. The simplified one-year model may be more suitable for evaluating the short-term productive investments like high yield seeds, and short-term CSA investments like drought-resistant seeds. The one-year simplified model will not be able to take into account setbacks due to losses if any in the first year. The long term models with simulated outcomes based on inflation and discount rate may provide a more realistic picture in terms of the farmer getting into a debt trap in certain cases if the initial years of high investment in CSA scenarios turn out to be bad years.

- Also, the economic benefits of reduced negative externalities or increased positive externalities have not been taken into account in the current risk framework for the cost-benefit analysis of the CSA Investments.

- The correlation between the severity of a bad year and the level of embedded protection of the CSA option also needs to be modeled and quantified. This will help to identify beyond what severity levels the existing embedded protection level of CSA may fail to deliver, thereby requiring Index Insurance for risk transfer.

- Lastly, it is important to understand that there is a spectrum of technologies between climate-smart and not climate-smart technologies and the features (costs, yields and embedded protection levels) of these technologies vary widely. Therefore, it is important to consider, quantity and take into account the costs, benefits and embedded protection specific to the underlying technology.

5. Conclusion

This report explores different factors that influence the ability of index-based insurance to promote investment in CSA. Until now, existing literature on index-based insurance has focused on increasing insurance uptake and identifying risks that affect the potential benefit of insurance. Our research aims to reframe the discussion around index-based insurance and shed light on the conditions under which insurance facilitates climate-smart investment.

We identify three key categories of exogenous variables that influence insurance's ability to promote climate-smart investment and how these variables affect the decision of whether or not to invest in CSA. The three categories are 1) weather and basis risk, 2) technology's cost, profitability, and embedded protection, and 3) risk exposure. Our model confirms that these factors have a significant ability to affect the risk mitigation potential of index-based insurance. Existing research does not provide an in-depth assessment on how variation in these factors affects the de-risking potential of index-based insurance.

We use existing research and two case studies on index-based insurance schemes in Ethiopia and Senegal to inform the development of our risk framework, as well as to assess the interactions between the factors affecting the effectiveness of index insurance in promoting climate-smart investment. The interactive risk framework, which can be modified to suit the needs of policymakers and project proponents, serves to help fill the research gap and provide policymakers with a tool to make more informed decisions regarding insurance.

The risk model framework simulates different scenarios and provides end users with the option to change key parameters. The model captures the costs and benefits of index insurance schemes and different agricultural technologies. The framework is a simplified one-year model that allows the policymaker to understand the underlying forces affecting the de-risking potential of CSA and insurance. The model aims to capture the farmer's decision-making process and incorporates the key factors affecting insurance's ability to incentivise climate-smart investments.

We observe that at low up to moderate levels of climate risk, insurance may have limited use to the farmer as the technology is able to mitigate risk. At low to moderate levels of climate risk, technology and insurance behave as supplements. At lower levels of climate risk, the profitability of technology is the key driver. At moderate levels of climate risk, the embedded protection of the technology becomes the key driver. Subsidizing technology rather than insurance may be more effective at low to moderate levels of risk, since technology subsidies may serve to: a) overcome risk exposure and the initial investment barrier; b) promote early adoption of CSA technologies; and c) increase the positive externalities that come with the technology’s adoption.

As climate risk increases, technology is unable to mitigate all risk. At high levels of climate risk, insurance and technology become complements and insurance may prove to be beneficial in covering tail-end or residual risk. Therefore, subsidizing insurance adoption at high levels of climate risk may be beneficial. At very high levels of climate risk, neither technology nor insurance may be able to mitigate risk, and farmers may need to seek out alternative sources of income or places to live. In such a case, governments may choose to direct funding to develop improved technologies, help farmers transition to other economic sectors, or even to assist farmers in migrating to other areas.

Lastly, while we observed that credit availability is an important driver due to the high cost of climate-smart technologies, the de-risking potential of index insurance and its usefulness in promoting CSA are highly dependent on the characteristics of the underlying technology, namely its cost, yield, and embedded protection to climate risks. Therefore, calibrating insurance indices to agricultural technologies and developing technology-linked insurance products may serve to account for residual or tail-end risks associated with a specific technology.

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8. Appendix

8.1 Investment Decision Framework

8.1.1 Stage 1: No Investments

No Productive Investments, No Insurance

To begin with, the farmer may decide to not make any investment, or very little investment. The farmer continues with business and growing as usual. She uses the most basic seeds, often left over from the past year's farming season, and depends on rain-fed irrigation. This indicates that the farmer makes no investments in CSA investments.

The farmer incurs a loan at a specified interest rate to procure the production materials. This is the lowest possible cost she can incur. The average yield is also the lowest across all the scenarios. The initial benefit of this scenario is hence the total production costs subtracted from the revenue earned. If there are savings, the initial benefit increases by the savings amount, which can help reduce the penalty the farmer faces in a bad year.

In a good year, this decision can prove to be highly fruitful for the farmer. If the farmer's expected revenue is greater than production costs, the farmer generates a positive benefit. In such a case, the farmer continues with business as usual, and makes a profit. But in the case of a bad year, or a weather disaster, due to the lack of a risk mitigation strategy, the severity of a bad year is very high (can be as high as 100%). This demonstrates that while the farmer can make a benefit in a good year, the loss in a bad year can be very high. In a bad year, the severity of the weather disaster affects the farmer's yield and reduces the initial benefit. If this initial benefit is negative, the farmer faces a penalty, which in turn further reduces her benefit.

In the case of a bad year or continuous bad years, a farmer may begin to wonder how to mitigate the risk of the bad year. Insurance is an option, but the cost of insurance will be too high given the risk factors. So the farmer, to safeguard her profit, will invest in technology.

8.1.2 Stage 2: Invest in Low-Cost Technology

Non-CSA Productive Investments without insurance

In the second stage, after weather disasters, the farmer implements a risk mitigation strategy by investing in non-CSA investments. The act of investing in non-CSA productive investments is considered risk reduction as it increases the yield but doesn't provide strong climate protection. For example, if the severity in the base case is 100% (where the farmer loses 100% of the yield), in this case, the severity is 60% (where the farmer loses 60% of the yield).

Hence, this increases the total production costs for the farmer, but also subsequently increases the average yield. Additionally, during a weather disaster it reduces the severity of the damage, which helps safeguard the farmer. In summary, the three differentiators from the first stage here are: increased cost, higher yield, and lower severity. The optional production subsidy can come into effect here (if applicable, to reduce the cost for the farmer)

In a good year, the farmer will reap the benefits of the technology with increased profitability, and as long as her revenue is greater than production costs, the farmer makes a positive benefit.

A bad year is trickier. The farmer does have increased embedded protection, due to the investment technology. But since this is low-cost, non-CSA investments, the embedded protection might not be enough to actually reap a benefit. In such a case, the farmer might be left with a loss and higher costs to pay (due to the investment in technology).

Hence, in such a scenario, the farmer can plan to either invest in insurance or in high-cost CSA technology. This will depend on the strength of the switch factors, as mentioned later. Let us assume the farmer invests in insurance. This brings us to stage 3.

8.1.3 Stage 3: Invest in Low-Cost Technology and Insurance

Non-CSA Productive Investments with Insurance

This is similar to the low-cost scenario above, but with one addition: that of insurance. In this scenario, apart from investing in Non-CSA productive investments, the farmer also buys insurance. Assuming the farmer has no savings, and there is no insurance subsidy by the government, she needs to borrow to cover the cost of the insurance as well. This increases the farmer's total production cost. By purchasing insurance, the farmer is creating a risk transfer mechanism, whereby during a bad weather year, the payouts from the insurance will transfer the loss to the insurer, and the farmer is safeguarded. This means the farmer is more risk-exposed and is attempting to spread her risk across various pathways.

Hence, in this scenario, the farmer has, as compared to stage one: increased production costs, additional insurance costs, higher yield, and lower severity. Additionally, in certain cases, the farmer may receive a payout from the insurance, which will increase the benefit. The optional production and insurance subsidy can come into effect here, if applicable, to reduce the cost for the farmer.

In a good year, the farmer, like the previous case, if the farmer revenue is greater than production costs, the farmer makes a positive benefit. But to note that this time, since the year is a good year, the farmer buys insurance but receives no payout. Hence, she has an increased production cost, but no additional benefit of the insurance in a good year. This can bring to question, in the farmer's mind, the benefit of investing in insurance.

In a bad year, the severity of the weather disaster affects the farmer's yield and reduces the initial benefit. If the bad year doesn't trigger the insurance to pay out, due to an inherent basis risk, the farmer will not receive any additional benefit from the insurance. Hence, similar to the previous sub-scenarios, if this initial benefit is negative, the farmer faces a penalty, which in turn further reduces his benefit. Hence, a high basis risk can yet again bring to question the benefit of insurance.

But if the insurance does payout in a bad year, it can potentially help the farmer create positive expected benefits and forgo the penalty. In such a case, the farmer's investment in insurance pays off, and she might have a positive, or non-zero benefit.
But in the event the basis risk is too high, or like in a good year, the yield even with the low-cost technology, isn't enough to justify the cost of the insurance and technology, the farmer might decide to invest in high-cost CSA technology.

8.1.4 Stage 4: Invest in High-Cost Technology

CSA Investments without Insurance

This stage adds another layer of complexity. The farmer invests in high-cost CSA as a form of risk mitigation. This assumes the farmer is aware of the climate risk that she faces and invests in ways to be prepared for it. This decision after the farmer finds that investing in low-cost technology and insurance is not a strong enough risk mitigation scheme to cover her from a weather disaster. By investing in CSA, she is actively mitigating risk by preparing for adverse climate years and reducing the expected loss from it. CSA increases the yield while additionally increasing embedded protection.

Hence, this is similar to the first stage scenario: the farmer faces increased production costs, but also higher yields, and lower damage (or severity) during a weather disaster. The difference is that the production costs are drastically higher than for non-CSA productive investments, as are the yields, whereas the severity is drastically lower.

In a good year, the farmer’s investment can bring her profitability. If the farmer’s revenue is greater than production costs, the farmer makes a positive benefit. If not, the farmer may question the benefit of the CSA technology.

In the case of a bad year, the CSA technology provides embedded protection that reduces the severity of the loss. But it doesn’t determine if the farmer’s expected benefit will be positive or negative. If positive, the farmer may be satisfied with the investments in CSA (where the expected benefit is positive). If the expected benefit is negative, the farmer may consider adding insurance as a further method of risk mitigation.

8.1.5 Stage 5: Invest in High-Cost Technology and Insurance

CSA investments with Insurance

In the last scenario, the model adds another layer of complexity. Apart from borrowing for productive investments, and CSA investments, the farmer purchases insurance as well. The differentiator is that the farmer has invested greatly in risk mitigation and transfer strategies. This assumes the farmer is aware of the climate risk that s/he faces and invests in multiple ways to be prepared for it. By purchasing insurance, the farmer is creating a risk transfer mechanism, whereby during a bad weather year, the payouts from the insurance will reduce the loss. By investing in climate smart agriculture, she is actively mitigating risk by preparing for adverse climate years and reducing the expected loss from it.

Hence, in this scenario, the farmer has, as compared to stage one: increased production costs, additional insurance costs, higher yield, and lower severity. Additionally, in certain cases, the farmer may receive a payout from the insurance, which will increase the benefit. The optional production and insurance subsidy can come into effect here, if applicable, to reduce the cost for the farmer.

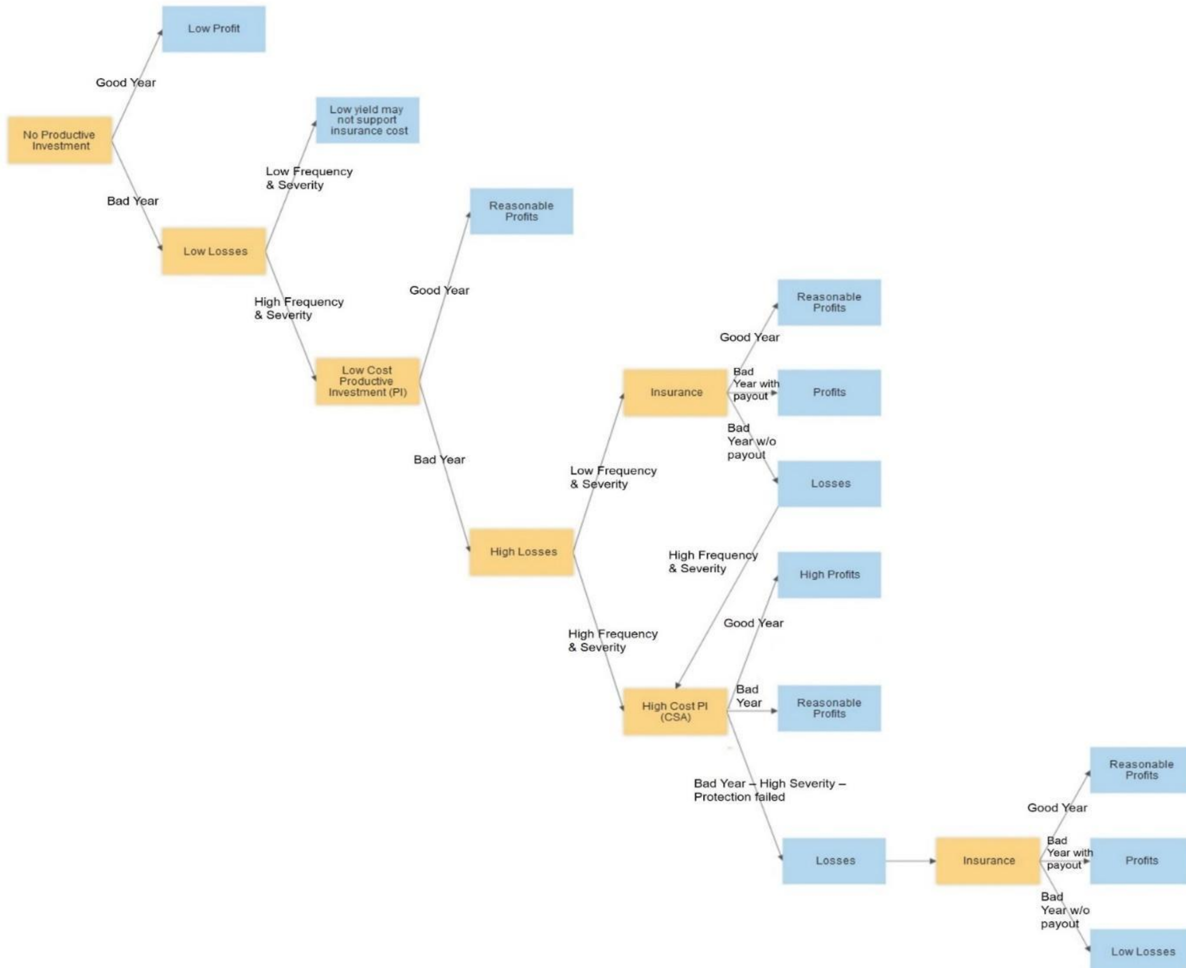
In a good year, the farmer buys insurance but receives no payout. Hence, she has an increased production cost, but no additional benefit of the insurance in a good year. If the farmer’s revenue is greater than production costs, the farmer makes a positive benefit. But in the case that the farmer’s revenue is less than the production costs, the farmer makes a negative benefit, and hence she incurs a penalty in the process, which reduces the benefit the farmer enjoys.

Finally, in a bad year, the farmer may either receive a payout, or not, depending on the basis risk. The severity of the weather disaster affects the farmer’s yield and reduces the initial benefit. If the bad year doesn’t trigger the insurance to pay out, due to an inherent basis risk, the farmer will not receive any additional benefit from the insurance. Hence, similar to the previous stages, if this initial benefit is negative, the farmer faces a penalty, which in turn further reduces his benefit. But due to the investments in CSA, the severity of the loss is much lower than any other scenario.

If the farmer does receive an insurance payout in this case. The insurance payout is calculated based on the payout coverage percentage as defined by the contract. This amount thereby is added to the initial benefit, increasing it. If this figure is greater than 0, then the farmer is free from facing a penalty. If this amount is negative, then the farmer faces a penalty, which reduces the benefit.

Combined expected benefit showcases the sum of the expected benefit or loss in the three sub-scenarios mentioned above. The aim is to model if, in a given period, insurance helps the profitability of the farmer and make the high investment in CSA investments worthwhile. A positive expected benefit showcases profitability, whereas a negative expected benefit tells us that insurance doesn’t de-risk Non-CSA investments.

8.2 Investment Decision Tree



8.3 Preliminary inputs assumptions (Ceteris Paribus Condition):

The one-year simplified model provides a set of dynamic input assumptions that can be changed to demonstrate the various investment strategies. We take some initial input numbers to define the ceteris paribus conditions for various switching point analysis.

As a preliminary assumption, the model assumes that the farmer does not have savings. Therefore, the entire amount of total cost (production + insurance, if any) will be borrowed at a specified interest rate, which we initially assume at 15% p.a. Further, the model assumes a probability of a bad year at 20%, or one in five years. With reference to index insurance costs and payouts, we chose close to real-world assumptions: 15% for loading, 66% payout probability in a bad year (i.e.33% basis risk), and payout coverage of 85% of the expected output. The average loss percentage taken for the purpose of insurance cost calculation is initially set at 85% of the expected output (equal to the initial payout coverage setting).

The production cost and related yield assumptions for the base case scenario is 150000:2 (total production costs: yield); for the less resilient-CSA productive investment scenario is 500000:7; for more resilient-CSA investment scenario is 900000:12. The cost and yield for the base case scenario have been taken as an approximate measure for rainfed rice production on a 1 Hectare of land without any productive investments (quality seeds and fertilizer). The cost and yield for the less resilient-CSA productive investment scenario were selected as an approximate measure for rice production on a 1 Hectare land where high-quality seeds, adequate fertilizer, and irrigation measures like furrow irrigation, etc. are being used. Similarly, the cost and yield for the more resilient- CSA investment scenario were chosen based on an approximate measure for rice production on a 1 Hectare land where high-quality seeds, adequate fertilizer, and drip irrigation are being used[6]. Embedded Protection that comes with investment in any scenario is defined as (1-severity of loss). The farmer loses 100% (severity) of the crop in a bad year in the base case scenario, 60% in the less resilient-CSA productive investment scenario, and 20% in the more resilient-CSA investment scenario. The model does not take into account the environmental benefits from the CSA adoption.

For most of the analysis, we assume no subsidies and add them to illustrate how the cost switch factor alters the scenarios. Further, for arriving at the final expected benefit of the

[6] CSA productive investments usually involve a long-term investment with some sort of asset creation that has a long useful life. The simple model that this paper presents uses a basic one-year model to evaluate and compare these various investment options. Therefore, we take the long-term asset creating CSA investments as the equivalent flow for the one-year model. For example: we may divide the approximate cost for drip irrigation equipment by its useful life of 10 years to arrive at the annual cost estimate for the CSA option.

scenarios we take into account the penalty (representative of the level of risk exposure) which is initially set at 100%.