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Feasibility study of a Risk Transfer solution in Democratic Republic of the Congo

RESUME

Mots clés : assurance indicielle, assurance paramétrique, agriculture, sécheresse, partenariat public-privé, analyse coûts-bénéfices, SPEI, soil moisture

L'assurance agricole se développe, tout comme les risques auxquels elle est confrontée en raison du changement climatique. Les pays en développement - déjà vulnérables - souffriront le plus d'une dégradation des conditions agricoles. Dans ce contexte, il est important de mettre en place des programmes de développement et des systèmes d'assurance pour protéger les agriculteurs des pays en développement. Cela leur donnera le temps de s'adapter aux nouvelles conditions climatiques, et de mettre en place des pratiques agricoles plus adaptées. Dans ce contexte, une institution bancaire multilatérale développe un programme de protection en République Démocratique du Congo à une échelle sans précédent, et cherche à optimiser une couverture pour protéger les agriculteurs contre la sécheresse.

Deux produits principaux sont développés dans le projet afin d'offrir la meilleure protection possible aux agriculteurs. Le premier est une assurance paramétrique, très intéressante dans la mesure où elle permet un paiement rapide sans avoir à certifier les pertes *via* des évaluations sur place par des experts, dans des zones difficilement accessibles. Le second produit est un fonds de réserve modélisé de deux manières différentes (autonome et assuré). Les deux produits sont en réalité complémentaires, dans la mesure où l'assurance est conçue pour couvrir des événements de faible fréquence/haute sévérité, alors qu'un fonds de réserve est conçu pour déclencher plus souvent pour des événements plus petits. Nous étudions donc comment combiner ces deux produits sur différentes couches de risque pour créer une couverture multicouche et optimiser la protection des agriculteurs en RDC.

Une fois les produits définis, nous passons à la structuration des couvertures, c'est-à-dire à la détermination des paramètres des couvertures pour l'assurance paramétrique et la réserve. Nous décrivons brièvement la modélisation des rendements et des indices, car il s'agit d'une première étape nécessaire pour pouvoir fixer le prix des couvertures, avant de nous concentrer sur l'assurance paramétrique. Un soin particulier a été consacré à la détermination du seuil de déclenchement à choisir - afin de s'assurer que la couverture ne dépasse pas le budget de 20 millions de dollars de prime sur les cinq ans - et des paramètres raisonnables pour la réserve (indemnité par personne, nombre de paiements par personne, point d'attache et de sortie).

Enfin, lorsque les produits sont définis et correctement calibrés, nous effectuons une analyse coûts-bénéfices. L'objectif est de trouver la meilleure configuration pour protéger les agriculteurs, du point de vue des agriculteurs. Nous partons d'abord d'un scénario de base - un scénario idéal construit à partir de plusieurs hypothèses, qui servira de référence. Ce cas de base permet de faire une première comparaison des solutions, et une analyse de sensibilité est effectuée ensuite pour assouplir les hypothèses (sur le changement climatique, l'élasticité des prix, etc.) afin de trouver la couverture la plus robuste et adéquate pour protéger les agriculteurs en RDC.

ABSTRACT

Key words: Index-based insurance, parametric insurance, agriculture, drought, public-private partnership, cost-benefit analysis, SPEI, soil moisture

Agriculture insurance is growing, as are the risks it faces because of climate change. Developing countries – already vulnerable – will suffer the most from a degradation of agricultural conditions. In this context, it is important to put in place development programs and insurance schemes to protect farmers in developing countries. This will give them time to adapt to new climatic conditions, and to put in place more adapted farming practices. In this context, a multilateral banking institution is developping a protection program in Democratic Republic of Congo at an unprecedented scale, and is looking to optimize a cover to protect farmers against drought.

Two main products are developed in the project in order to give the best protection as possible to farmers. The first one is a parametric insurance, very interesting to the extent that it enables quick payout with no loss assemsment, in zones hardly accessible. The second product is a reserve fund modelled in two different ways (standalone and insured). Both products are in reality complementary, to the extent that insurance is designed to cover low frequency/high severity events, where a reserve fund is designed to trigger more often for smaller events. We thus study how to combine those two products on different risk layers to create a multilayer cover and optimize coverage for farmers in DRC.

Once the general products are defined, we move on to cover structuring, *i.e.* determining the details of covers for parametric insurance and reserve. We briefly describe yield and index modelling, as it is a necessary first step in order to be able to price the covers, before focusing on parametric insurance. Time in particular have been dedicated to determining trigger threshold to chose - in order to ensure the cover does not exceed the budget of $20 million premium over the five years – and reasonable settings for reserve (indemnity per person, number of payouts per person, attachment and exit point).

Finally, when products are defined and properly calibrated, we run a cost-benefit analysis. The goal is to find the best set-up to protect the farmers, from the farmers' perspective. We first proceed from a Base Case – an ideal scenario built from several hypothesis, that will be used as reference. This Base Case enables to do a first comparison of the solutions, and sensitivity analysis is run to relax hypothesis (on climate change, price elasticity, *etc.*) in order to find to most robust and adequate cover to protect farmers in DRC.

ACKNOWLEDGEMENTS

There are so many people to thank for the help they gave me all along this beautiful project, that I will unfortunately not be able to cite them all. I think fair to first thank Stéphanie Dausque and Quentin Favre, who really showed me how interesting the work of an actuary can be.

I think fair, then, to thank Eliot Pernet and Suzanne Bourgault, with whom we made – I believe – a great team for this DRC project. Since I agreed not to disclose our client’s name, I cannot mention our contact there by name…she was however very impressive and helpful, and I thank her as well.

I would also like to thank all the people at AXA Climate who enabled me to join (because it begins by that), to upgrade my skills and to discover the work of an underwriter. It has been nearly two years so there are quite many people I have in mind, but I would particularly like to mention: Gwendal Pougnet, who trusted me two years ago by offering me an internship, Charlotte Belin, my priceless tutrice, Boris Rohde and Fabien Berciaud, because we do have a good EMEA team.

I thank, more generally, the whole AXA Climate team, because we all grow together and any achievement is a collective one.

Finally, on a lighter note, I thank any eventual reader for his patience and understanding. I did my best to make it clear.

TABLE OF CONTENTS

TABLE OF ABBREVIATIONS

CARD	Climate Adaptation in Rural Development
CBA	Cost-Benefit Analysis
CDF	Franc Congolais
CLM	Community Land Model
CMIP	Coupled Model Intercomparison Project
CSA	Climate-Smart Agriculture
DRC	Democratic Republic of Congo
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF Reanalysis 5th Generation
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
LPJML	Lund-Potsdam-Jena managed Land
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
PMFBY	Pradhan Mantri Fasal Bima Yojana (Indian national crop insurance scheme)
RCP	Representative Concentration Pathway
USD	U.S. Dollar
SIF	Solar Induced chlorophyll Fluorescence
SMI	Soil Moisture Index
SPEI	Standard Precipitation Evapotranspiration Index
WRSI	Water Requirement Satisfaction Index

TABLE OF FIGURES

LIST OF TABLES

GENERAL INTRODUCTION

This introduction aims at giving a general overview of the context in which this report was written, and give a grasp of the different matters at stake that motivated the study. First we will give some key elements about global warming, and then the impact this climate change could have on agriculture. This will show that agriculture needs insurance to face this new issue, which logically will bring us to give some key elements about insurance in agriculture, and introducing the type of insurance that will mainly be discussed in this report : parametric insurance.

1. Global warming

Global climate is warming, there is no denying that. Latest IPCC report, published in summer 2021, established that :

- Global warming is real
- It is due to human activities.

This being said, it can be useful to begin this report with some figures. A first way to consider this global warming is by looking directly at sea temperature. This is a good alternative to air temperature since it shows less volatility and enables to better see the trend of the past century. This data is publicly available on the US National Oceanic and Atmospheric Administration (NOAA)[1], and enables to build Figure 1 below.

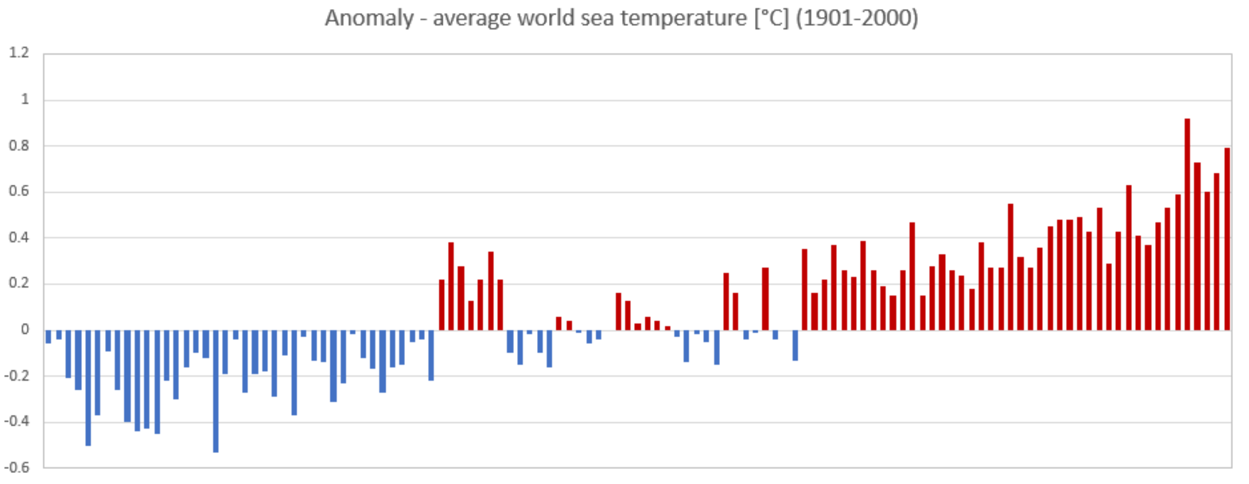

Figure 1: Monthly average sea temperature anomaly, worldwide, compared to 1901-2000 average
Source: NOAA

Global warming in itself is not a “good” or a “bad” thing. Earth has been through numerous climatic cycles, alternating ice ages and warmer periodes. This is partly due to positive feedback loops, that tend to accelerate a trend once it is in motion (more warming creating more warming) – until the cycle reverses. One key contributor in these cycles is the infamous CO_2, which participates to global warming because of its capacity to retain warmth into the atmosphere : this is why it is called a greenhouse gaz.

It is possible to compute the anomaly of CO_2 concentration in the atmosphere, just as was done for sea temperature, and compare the shape of the two curves (see Figure 2 below). This data also comes from public sources[2].

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[1] https://www.ncdc.noaa.gov/cag/global/time-series/globe/ocean/1/1/1880-2022

[2] https://ourworldindata.org/atmospheric-concentrations and https://gml.noaa.gov/ccgg/trends/data.html

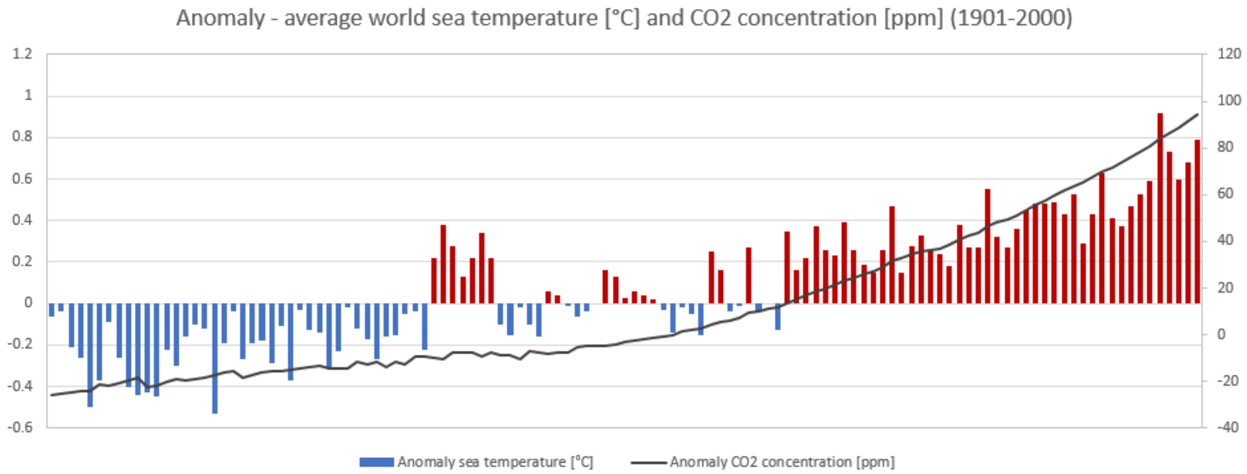

Figure 2: Sea temperature and CO_2 concentration anomalies, compared to 1901-2000 average
Source: NOAA

There is a similarity in anomalies trends, both on sea temperature and CO_2 concentration in the atmosphere, that helps understanding the links between the two variables. Although correlation is no causality, wide scientific consensus enables, in that precise case, to say that CO_2 concentration in the atmosphere is causing global warming (even though it is not the only cause, obviously).

What makes this warming episode different from the usual cycle, however, is its speed. Indeed, the historical warming cycles Earth has experienced had the same order of magnitude in terms of speed and intensity, which is roughly +5°C in 100 000 years. Lately (since 1850), Earth global average temperature has increased by +1.1°C: this is unprecedented. The causality established between CO_2 concentration and global warming can help getting a better grasp of what is actually happening (see Figure 3 below):

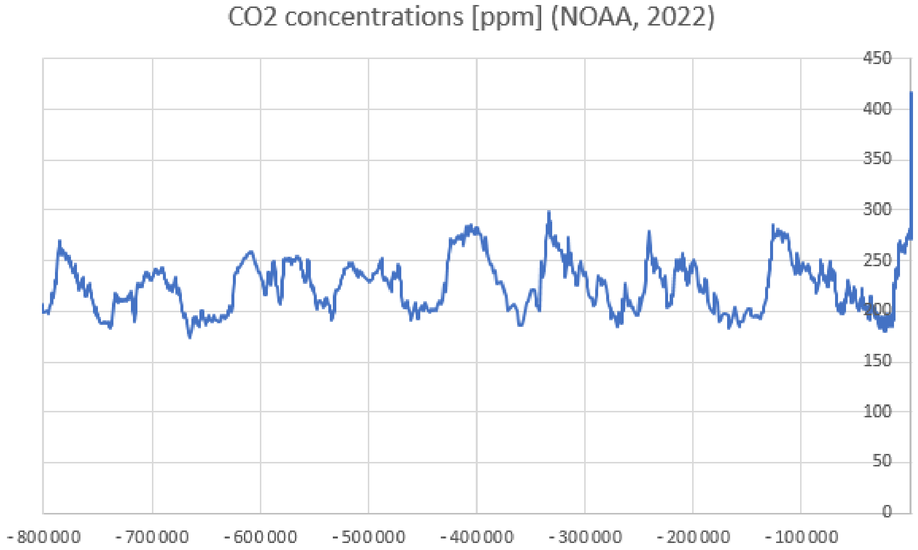

Figure 3: CO_2 concentration in atmosphere, in ppm, since 800 000 B.C.
Source: NOAA

2. Consequences for agriculture

This global warming will obviously have an impact on agriculture, since the consequences are not restrained to increase of temperature. The following list gives some examples of impacts (depending on the regions, of course) :

- More violent cyclones: increase of sea temperature could indeed increase probability of more violent cyclones due to more evaporation. Aside from the danger cyclones represent for people, houses and infrastructures, they also have a potential impact on agricultural activities (uprooting fruit trees or destroying cultures, due to wind or flood).
- More frequent heatwaves: in agriculture, depending on the phenological phase of the crop, heatwave can be a real threat to crop development.
- Sea level rise: deltas are very fertile zones, and wide populations directly depend on it. These areas are however very sensitive to sea level rise. Moreover, salted water flooding damages soils, which can have a short term effect on agriculture yields.
- Desertification: no need to further explain how this could be a threat to agriculture.
- Freshwater shortages: freshwater is pretty rare on Earth, and very unequally distributed. The vast majority of irrigable zones are already irrigated, and this technology does not provide solution for shortages to come. Finally, lots of crops depend on underground phreatic tables, which are depleting as well.

These different changes will necessitate tremendous adaptation measures, which will have to be taken locally. Generally speaking though, crop migration might become necessary in order to use crops that are adapted to new climatic conditions. This seems like an adequate moment to mention that agriculture basically feeds humanity, it is thus paramount to protect it accordingly. We all depend on it, however once again the first who will suffer are populations in developing countries. It is pretty simple to see that the more a population is vulnerable, the more it relies directly on agriculture. World Bank database enables to get both GDP per capita[3] as well as the percentage of GDP coming from agriculture[4]. It is interesting to see how this percentage evolves against GDP per capita (Figure 4):

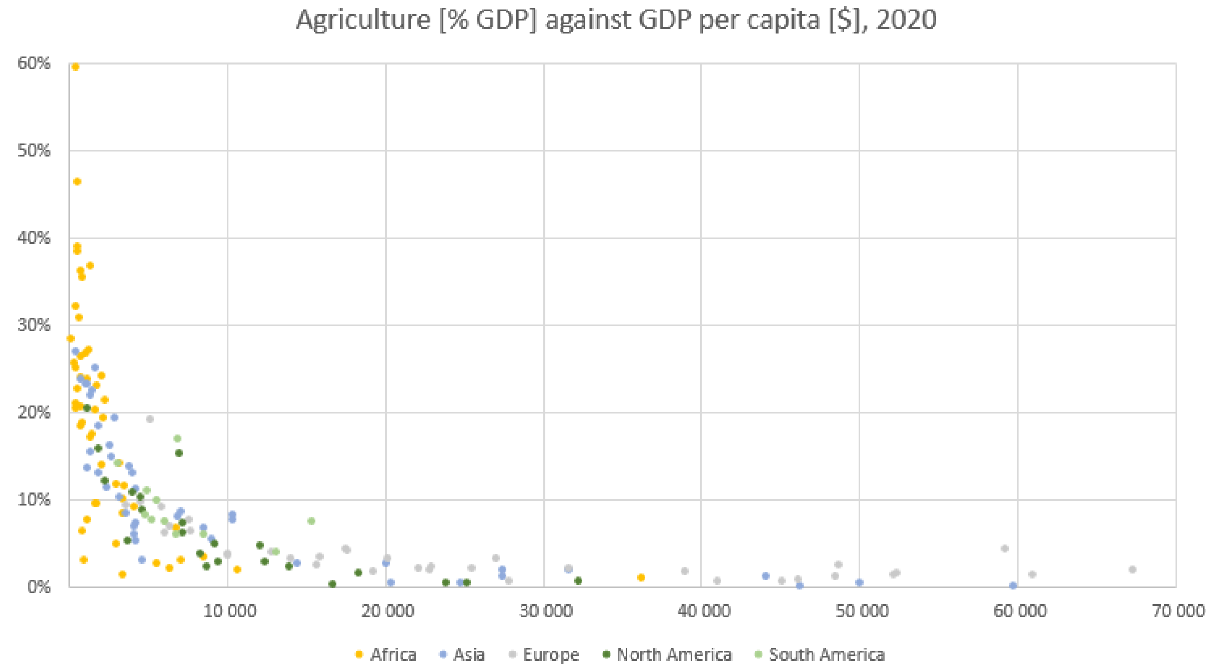

Figure 4: Agriculture value added (% of GDP) against GDP per capita ($), 2020
Source: AXA Climate

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[3] https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
[4] https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

Figure 4 shows an interesting dynamic, which is that agriculture in a country's economy seems inversally proportional to the overall wealth of its inhabitants (GDP per capita). It appears that country with a low GDP per inhabitant, mainly located in Africa, Asia and South America, are the ones that rely the most on agriculture, but also the ones that were already the more vulnerable to climate change. This is the reason why it is important to implement development schemes and insurance, in ordre to protect local population against yields dropdowns.

3. Traditional insurance in agriculture

Previous subsection shows that there is a strong need of insurance in agriculture. There are, obviously, traditional solutions dedicated to agricultural activities. The list below is organized from the more targeted cover, to the more holistic:

- Named-peril crop insurance (NPCI): this kind of insurance only covers losses due to specific perils, pre-determined in the insurance contract. This product is widespread, and is very adapted to very destructive and localized perils (such as hail or frost).
- Calamity-based crop insurance (CBCI): is very similar to the cover above, although more adapted for perils with a wider range of action (cyclone, drought, flood). Indeed, the first trigger of such a cover is a calamity declaration procedure from government.
- Multiperil crop insurance (MPCI): multiperil crop insurance is the oldest and most common form of crop insurance. This cover protects the yield, regardless of the event that triggered a bad harvest (except potential exclusions).
- Revenue/Income insurance: these covers protect directly farmers' revenues. The difference between revenue and income is that the first one is based on gross sales, whereas the second one is based on gross sales net of expenses. The advantage of these covers is that they take into account variability of commodity price, protecting more some covers protect directly farmer's revenue, integrating commodity price variation in the cover. This type of insurance is developing lately due to high crop price volatility.

These products are widely sold around the world, even though there exist some other solutions. In order to have an idea of the evolution of this market, it is interesting to look at premium volume evolution. It is always complicated to have a clear view of the volume of premium of one particular type of insurance, however HOHL [2019] made a study in his book, in which he displays the following chart (Figure 5):

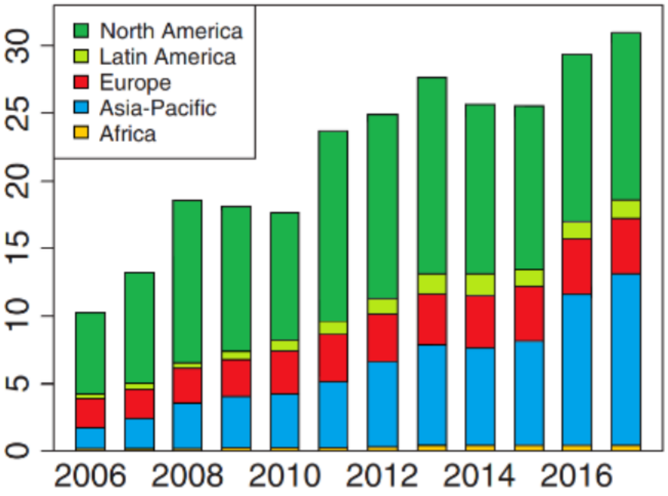


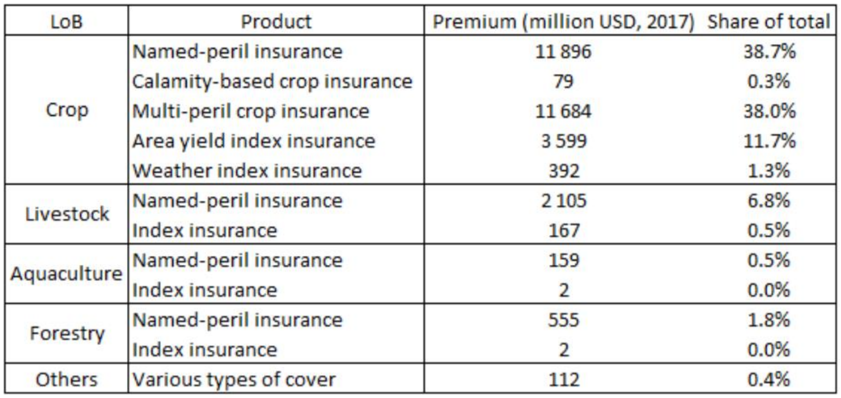
Figure 5: Agriculture insurance premium evolution (millions USD) by geographical zone
<u>Source</u>: Derived from HOHL [2019], p.156

Figure 5 shows that crop insurance premium, worldwide, have tripled over the last 10 years. Developed markets (Europ, North America) are already saturated and show nearly no evolution on this period. Emerging markets, on the other hand, show sharp increase – especially in Asia. This would lead to think that a similar transition period could be expected from markets in Africa and South America.

Despite this evolution, there are certain limits to traditional insurance that quickly come to mind. The main issue – and characteristic – of these covers is that loss amount is based on insured's declaration. For NPCI for instance, how is it possible to assess that insured indeed lossed 50% of his harvest due to hail alone? For MPCI, could it be that yield dropdown is due to changes in agricultural practices and not weather conditions (e.g. use of a different fertilizer)? There are of course controls and inspector whose job is precisely to answer those questions, however this introduces extra costs and the opportunity to highlight the two main limits of traditional insurance :

- Moral Hazard: this notion, credited to the 18th century economist Adam Smith (*cf.* MARTEAU [2012]), is defined as "the maximization of individual self-interest with no regard to the adverse consequences on collective utility". In the context of insurance, this corresponds to the insured endorsing more dangerous behaviours, because he knows he is covered by insurance in case of an event.
- Anti-selection: consequence of asymmetric information about the insured's risk. If the insured knows better his risk than the insurer, they are able to make arbitrage by taking advantage of a contract that underestimates their risk. In case of an error in pricing, the insurer can retain only "bad risks", which will have a negative impact on its profitability. If, moreover, the pricing has a bias that tends to underprice a whole area, there is the risk of accumulating underpriced contracts in the same zone, creating accumulation bubbles that the insurer is not aware of.

It is thus very important, for indemnity insurance, to be able to have a control over the insrued's declaration. This however creates an additional cost – both in terms of money and delay to receive indemnity. This is all the more true for remote places and developing countries, where it might be tricky to organize proper controls. From this remark it is interesting to have a look at how the $30 million are distributed between the different crops and type of insurance (Table 1 below):



LoB	Product	Premium (million USD, 2017)	Share of total
Crop	Named-peril insurance	11 896	38.7%
	Calamity-based crop insurance	79	0.3%
	Multi-peril crop insurance	11 684	38.0%
	Area yield index insurance	3 599	11.7%
	Weather index insurance	392	1.3%
Livestock	Named-peril insurance	2 105	6.8%
	Index insurance	167	0.5%
Aquaculture	Named-peril insurance	159	0.5%
	Index insurance	2	0.0%
Forestry	Named-peril insurance	555	1.8%
	Index insurance	2	0.0%
Others	Various types of cover	112	0.4%

Table 1: World aggregated agriculture premium (million USD) per type of crop and insurance
Source: Derived from HOHL [2019], p.158

Table 1 shows that approximately 13.5% of all premium come from a rather recent type of insurance, which is index insurance (also known as parametric insurance). The goal of this type of covers is to overcome the limits of traditional insurance, proposing a new way of calculating insurers' losses.

4. Parametric insurance

Traditional insurance is declaration based. The insured declares a loss and receives an indemnity accordingly. Parametric insurance works differently, since the claim is actually calculated from a pre-defined climatic index. In order for this kind of cover to be efficient, there is a mutual work to be done between client and insurer in order to agree on:

- One (or several) parameter(s): a parameter is a climatic variable – rainfall, temperature, wind – that has to be independent from both the insured and the insurer. This parameter needs to be the closest one to the insured's risk, in order to reflect as accurately as possible its real risk. Data is provided by a third party, most of the time a public institution which data is open source.
- An index: the index is the value that will be used to compute the claim. It is a transformation of the parameter (monthly average temperature, cumulated rain over a three days moving window, maximum wind gust over a given period of time, etc…). If there is a limited number of possible parameters, there could be considered to be an almost infinite number of index.
- Payout structure: in order to compute the claim of the insured based on the index, a payout structure is necessary. Several elements are, most of the time, needed in order to build such function:
    - The trigger is the index value from which a loss is considered to have happened. Before the index crosses the trigger, no payout will be due.
    - The exit is the index value beyond which the claim does no longer increase. This means that for any given value exceeding the exit point, the claim will remain the same.
    - Of course a structure is necessary for index values between trigger and exit. It can be a linear interpolation or a structure by steps.

To visualize better the way it works, Figure 6 below shows two examples of structures:

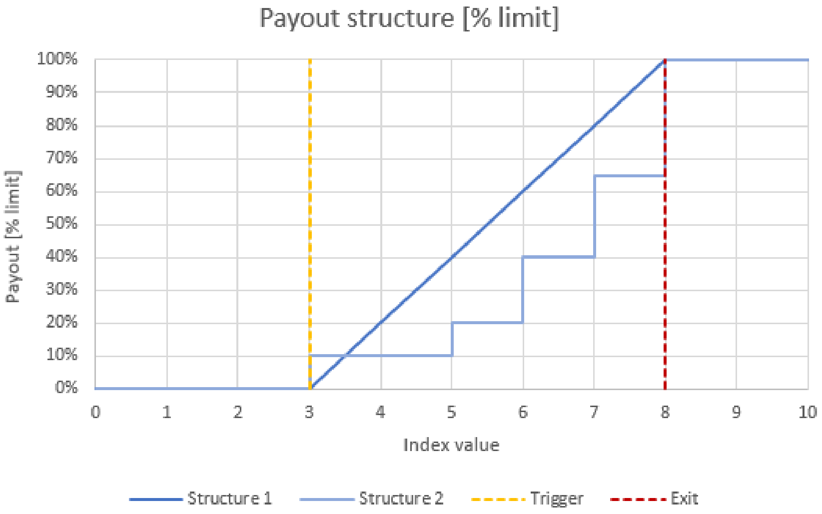


Figure 6: Example of payout structure for parametric insurance (structure 1 is linear, structure 2 is by steps, trigger at 3 and exit at 8)
<u>Source</u>: *AXA Climate*

Index and payout structure enable to build a parametric cover that will fit best to insured's needs. Most of covers are tailor made to take into account each insured risk and risk appetite. There are multiple advantages to such covers:

- Trust: data comes from a third party and unbiased source. In addition, climate index cannot be manipulated by the insured or the insurer. This creates a relationship of trust between the insurer and the insured.
- Speed: there is no need for a second opinion or on-site loss assessment by an expert. Simply looking at the value of the index is sufficient to determine the insured's claim. This system enables to compensate insured within a few days after data publication.
- Availability: traditional insurance cannot cover certain risks. Parametric insurance allows more risks to be covered as long as the data is available. The expansion of satellite constellation and data opens up a wide range of possibilities to create parametric covers in places where loss assessment is challenging.
- Symmetry of information: if the contract is signed long enough before the inception of the coverage period, the policyholder has no more information about his risk than the insurer.

The major disadvantage of parametric insurance is that the policy so constructed will never cover exactly the risk to which the policyholder is exposed. This possibility of inadequation between the insured actual loss and the claim calculated with the index is called the basis risk. This makes it very important to ensure a very high correlation between the index and the insured's losses. The basis risk can be of three different natures (*cf.* SADOU [2017]):

- Temporal: this encompasses the risk that the loss happens outside of the risk period agreed on the contract. A good example is vineyards frost parametric insurance in France, which risk period begin most of the time early April. However if end of winter is mild, budding can happen during March, and a frost event end of March would then be destructive even though it is not covered.
- Spatial: it is very often difficult to get precise climatic measures at insured's site. Very often, it is necessary to proceed from nearest meteorological station, or reanalysis data. There is then a risk that a very localized event occurs that is not accurately reflected in the proxy data.
- Model: if the index does not accurately reflect the insured's risk and correlation between index and loss is not good enough.

This basis risk is really a pain point on an economicial point of view. KAHNEMAN et TVERSKY [1979] works on risk perception and decision under risk enable to say that for a same utility, an "average" individual will prefer an indemnity that exactly corresponds to his loss rather than a more probabilistic claim based on a climatic index. As a conclusion, a World Bank report (*cf.* WORLD BANK [2005]) synthesizes the advantages and challenges of index insurance (Table 2 below):

Advantages	**Challenges**
Less moral hazard The indemnity does not depend on the individual producer's realized yield.	*Basis risk* As discussed above.
Less adverse selection The indemnity is based on widely available information, so there are few informational asymmetries to be exploited.	*Precise actuarial modeling* Insurers must understand the statistical properties of the underlying index.
Lower administrative costs Underwriting and inspections of individual farms are not required.	*Education* Users must be able to assess whether index insurance will provide effective risk management.
Standardized and transparent structure Contracts can be uniformly structured.	*Market size* The market is still in its infancy in developing countries and has some start-up costs.
Availability and negotiability Standardized and transparent, the contracts may be traded in secondary markets.	*Weather cycles* Actuarial soundness of the premium could be undermined by weather cycles that change the probability of the insured events, such as El Niño, for example.
Reinsurance function Index insurance can be used to transfer the risk of widespread correlated agricultural production losses more easily.	*Microclimates* These production conditions make rainfall or area-yield index based contracts difficult for frequent and localized events.
Versatility Index contracts can be easily bundled with other financial services, facilitating basis risk management.	*Forecasts* Asymmetric information about the likelihood of an event in the near future creates the potential for intertemporal adverse selection.

Table 2: Advantages and challenges of index insurance
Source: Adapted from WORLD BANK [2005], p.18

* * *

This general introduction aimed at showing that agriculture insurance is growing, as are the risks it faces because of climate change. Developing countries – already vulnerable – will suffer the most from a degradation of agricultural conditions. In this context, it is important to put in place development programs and insurance schemes to protect farmers in developing countries. This will give them time to adapt to new climatic conditions, and to put in place more adapted farming practices. The present report is the result of a Cost-Benefit Analysis (CBA) conducted for a multilateral international development bank, which shall remain anonymous and will be referred to as "the Client" throughout the present report. The Client is putting in place a protection and development scheme at an unprecedented scale in Democratic Republic of the Congo (DRC), and the goal of this study is to optimize the protection of the cover from the perspective of the farmers.

1 – REPORT SCOPE

This section introduces the project of this report, and describes the global parameters and assumptions used throughout the document. The first subsection gives the general context, and the last two subsections focus on demographic and agricultural parameters, which will be used for all the products and scenarios to come.

1. Report context

The overall project

The client supports an agriculture development program in DRC. Focus is made on the protection of farmers' income during the investment phase prompted by the program. Farming income is indeed primarily dependent on the climatic shocks to which farmers are exposed, which can drastically affect their yield. This vulnerability is even more critical insofar as the vast majority of DRC farmers does not yet have adopted climate-smart techniques (drought-resistant seeds, irrigation systems, water reserves, etc.). It is therefore necessary to secure farmers' modernization efforts through an income protection scheme.

The feasibility study

A feasibility study for a risk transfer solution has been conducted on demand of the Client, following a pre-feasibility study conducted by a major actor of parametric insurance. This report uses numerous results and hypothesis made in the previous prefeasibility study, each and everyone being identified as such and citing this prefeasibility as source.

The present report

The present report focuses on the cover design and optimization part of the feasibility study, leaving the operational aspect on the side on demand of the Client. This still leaves plenty of topics to rise, and numerous issues to identify and solve. Indeed, once the necessity of protecting farmers' income has been highlighted, how best to do so? The simplest option is to set up a reserve fund, *i.e.*, a sum of money that can be drawn on in the event of a climate shock. Another option is to use an insurance scheme. The disadvantage of insurance is that it requires a financial contribution (premium) even in the absence of a disaster leading to a payout, but it has the considerable advantage that it can make much larger payments than the reserve fund in the event of an extreme climate shock.

Overall, there are several potential ways to protect farmers in DRC. The following solutions have been explored and compared through a Cost-Benefit analysis:

- A $10 million reserve fund, not insured (standalone);
- A $10 million reserve fund, insured;
- A Parametric Design #1, relying on an evapotranspiration index (based on data provided by pre-feasibility study) and triggering at territory level;
- A Parametric Design #2, based on soil moisture, triggering at province level and with a differentiated limit per crop (higher payout for cassava than maize);
- A Parametric Design #3, based on soil moisture, triggering at territory level and with a differentiated limit per crop.
- Several hybrid schemes, combining a reserve fund and a parametric insurance cover.

Parametric insurance presents itself as a quick and objective option for compensating farmers: in the event of a drought observed by satellite, compensation can be triggered in just a few days without onsite damage assessment. However, in the absence of historical yield data in the DRC, it is not possible to reliably estimate the correlation between the satellite data and the farmers' yields. This leads to a high degree of basis risk.

In this context, it seemed appropriate to reserve parametric insurance for rare and severe events. There are two main reasons for this. First, these events are better captured by the parametric index than less extreme events. Second, the magnitude of these events calls for a higher compensation, which only insurance can offer. Complementary to the insurance scheme, we propose that the $10 million of the reserve fund can be activated by "soft trigger" when the humanitarian situation requires it.

2. Demographic parameters

The solution will focus on 4 provinces, for a total of 26 territories (see Figure 7 below):

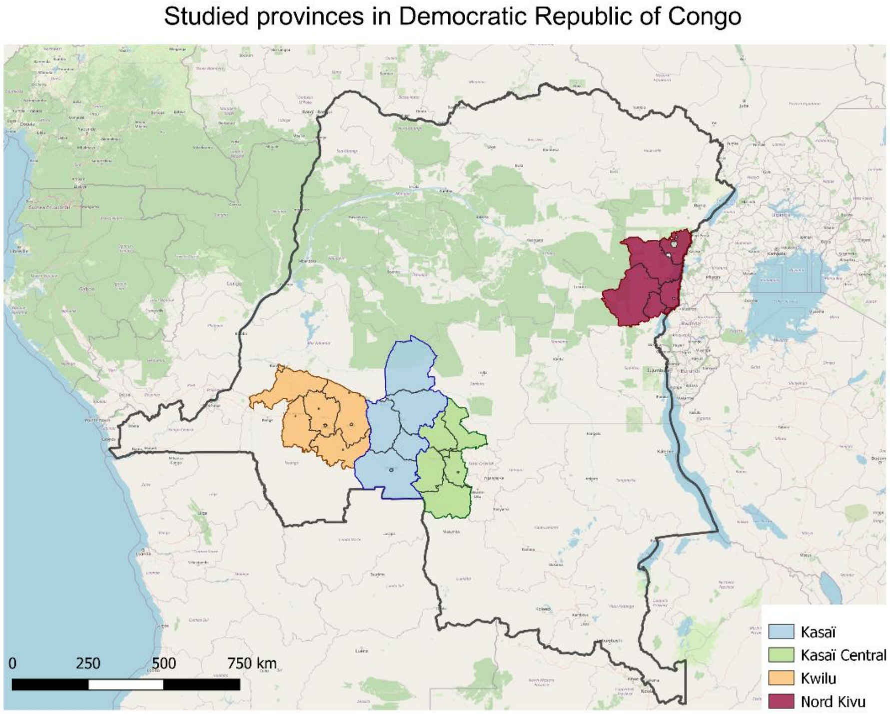
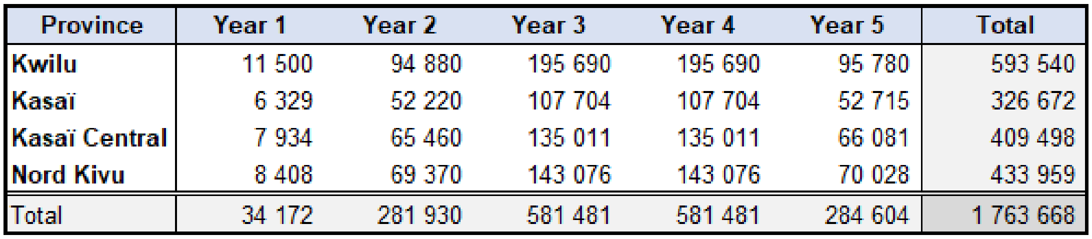


Figure 7: Geographical scope of study
Source: AXA Climate

We determine the exposure at the territory level, using two tables provided by the Client. The first one shows the onboarding schedule of new beneficiaries per province (Table 3):



Province	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Kwilu	11 500	94 880	195 690	195 690	95 780	593 540
Kasaï	6 329	52 220	107 704	107 704	52 715	326 672
Kasaï Central	7 934	65 460	135 011	135 011	66 081	409 498
Nord Kivu	8 408	69 370	143 076	143 076	70 028	433 959
Total	34 172	281 930	581 481	581 481	284 604	1 763 668

Table 3: Onboarding schedule of new beneficiaries, by province
Source: Client

To allocate these farmers to territory, we use the following table (Table 4):

Province	Territory	Cumulated number of farmers
Kwilu	Bagata	38 554
	Bandundu	78 382
	Bulungu	48 353
	Gungu	92 299
	Idiofa	93 391
	Kikwit	135 914
	Masi-Manimba	106 647
Kasaï	Dekese	22 212
	Ilebo	73 930
	Kamonia	67 863
	Luebo	60 260
	Mweka	91 751
	Tshikapa	10 656
Nord Kivu	Beni	44 597
	Goma	7 979
	Lubero	83 957
	Masisi	89 148
	Nyiragongo	92 190
	Rutshuru	49 089
	Walikale	66 999
Kasaï Central	Demba	29 028
	Dibaya	46 896
	Dimbelenge	72 130
	Kananga	28 252
	Kazumba	137 321
	Luiza	95 870
	Total	1 763 668

Table 4: Repartition of farmers in program by territory
Source: Client

These tables show that the program is expected to cover 1,763,668 farmers over five years. We can note that Kwilu gathers a third of all farmers, and the territory that has the largest number of farmers is Kazumba, in Kasaï Central province (see Figure 8 below):

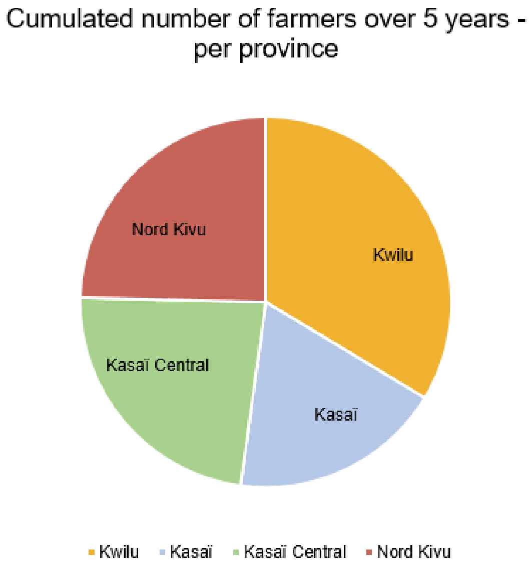


Figure 8: Cumulated number of farmers over 5 years per province
Source: Client

3. Agricultural parameters

Two crops are considered in this study: cassava and maize. As the purpose of this study is to estimate the relative cost and benefits of different protection schemes, the revenues of farmers must be estimated to model the benefits of each instrument. To do so, we use the following formula:

$$Revenue_{farmer} = \sum_{crops} Yield_{crop} \text{ x } Price_{crop} \text{ x } Superficy_{crop}$$

Several data are needed at *crop x territory* granularity. The following paragraphs detail how these data have been obtained.

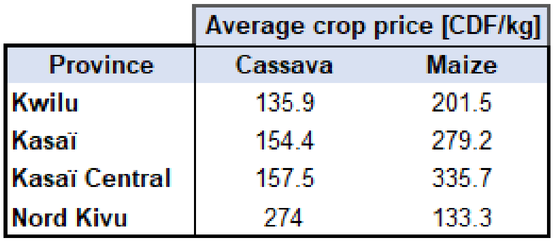
a. Yields [t/ha]

In the absence of real yield data, the “historical” yields used come from the prefeasibility study, which were estimated from a widely used drought index: SPEI, calculated following method described by BEGUERÍA et AL. [2014]. We consider these historical yield as valid historical data. This choice was made as, in the absence of historical yield data, it is not possible to calculate the error of these estimations and excess of rainfall is challenging to estimate based on re-analysed data with low spatial resolution.

SPEI-modelled yields are available for both crops, between 1981 and 2019, for 23 territories out of the 26 we focus on. The three territories lacking data are Goma, Kikwit and Tshikapa. Since these territories are located in different provinces, we consider that the yield for each of them is the average of their province yield. This hypothesis seems reasonable as the correlation between territories of a given province in a given crop is very strong.

b. Prices [USD/t]

Our assumption on crop prices come from the prefeasibility study. They are gathered in the table below (Table 5):



	Average crop price [CDF/kg]	
Province	**Cassava**	**Maize**
Kwilu	135.9	201.5
Kasaï	154.4	279.2
Kasaï Central	157.5	335.7
Nord Kivu	274	133.3

Table 5: Average crop price by province, CFD/kg
<u>Source</u>: *Prefeasibility study*

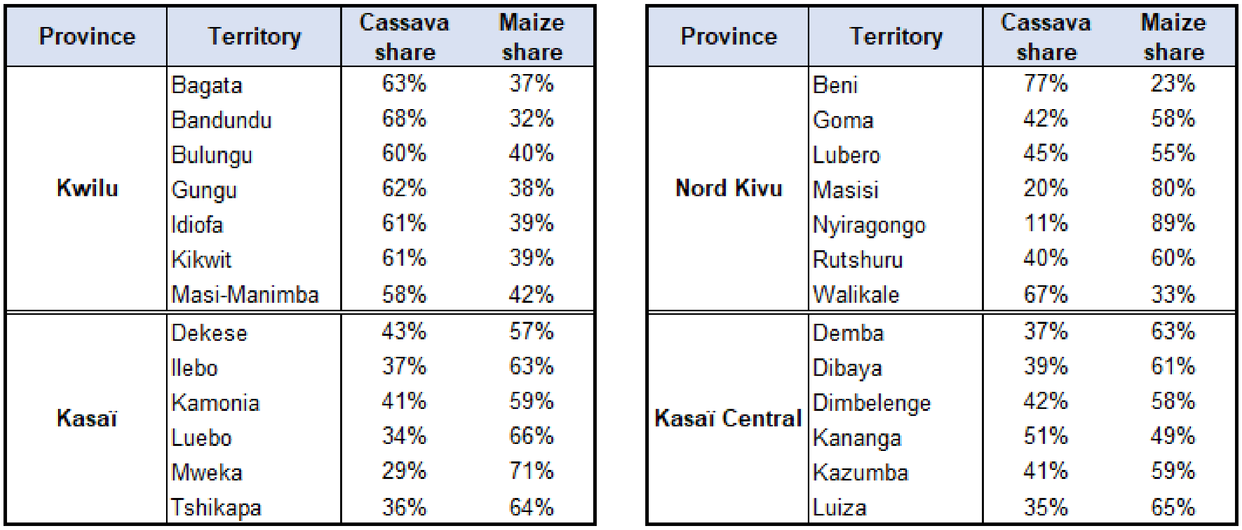
To convert these average prices to USD/t, we use the exchange rate as of June 2021 between Francs Conglais (CDF) and dollars (USD), which is approximately 0.0005.

We note that these average prices are based on a 2012 survey. An improvement to better reflect farmer’s revenues would be to model the latter from more recent crop prices.

c. *Superficy [ha]*

Planted areas by territory and by year can be deduced thanks to the participants assumptions and the assumption that each farmer owns in average a 0.33ha parcel. This however does not enable us to determine the share of maize and cassava grown in each area. This is a key point to consider since cassava yield and price differ from maize, and a territory's revenue will behave differently according to the share of each crop.

To estimate the split between cassava and maize, we use the pre-feasibility study's estimate of superficies by crop and by territory (see Table 6 below). For the three territories where data were not available, a province average was taken.



Province	Territory	Cassava share	Maize share
Kwilu	Bagata	63%	37%
	Bandundu	68%	32%
	Bulungu	60%	40%
	Gungu	62%	38%
	Idiofa	61%	39%
	Kikwit	61%	39%
	Masi-Manimba	58%	42%
Kasaï	Dekese	43%	57%
	Ilebo	37%	63%
	Kamonia	41%	59%
	Luebo	34%	66%
	Mweka	29%	71%
	Tshikapa	36%	64%

Province	Territory	Cassava share	Maize share
Nord Kivu	Beni	77%	23%
	Goma	42%	58%
	Lubero	45%	55%
	Masisi	20%	80%
	Nyiragongo	11%	89%
	Rutshuru	40%	60%
	Walikale	67%	33%
Kasaï Central	Demba	37%	63%
	Dibaya	39%	61%
	Dimbelenge	42%	58%
	Kananga	51%	49%
	Kazumba	41%	59%
	Luiza	35%	65%

Table 6: Expected share of harvested area between cassava and maize by territory
<u>Source</u>: *Prefeasibility study*

Table 6 is useful to determine the distribution key of planted areas at territory granularity between cassava and maize. We apply these share to the superficies by territory based on Table 3 and Table 5 (using the hypothesis that a farmers owns in average 0.33ha).

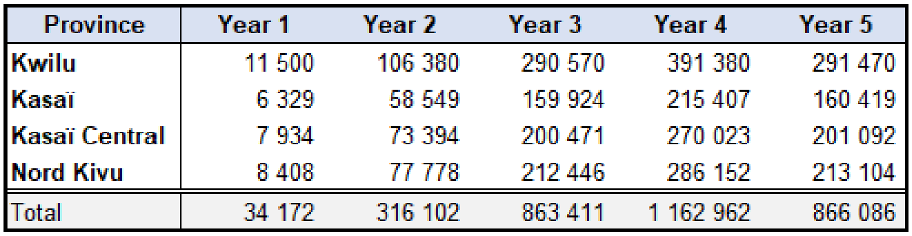
2 – PRODUCTS DEFINITION

This section defines the two main products developed in the project. The first one is a parametric insurance. The first subsection details this insurance solution and the two different parametric designs that have been built. The second product, a reserve fund modelled in two different ways (standalone and insured), is detailed in the second subsection. Finally, the last subsection focuses on how to combine parametric insurance and reserve to create a multilayer cover and optimize coverage for farmers in DRC.

1. Parametric insurance

a. General information

$20 million is dedicated to pay insurance premium in order to protect farmers over five years. Each farmer is enrolled for two years, resulting in the following expected number of insured per year from Table 3 (Table 7):



Province	Year 1	Year 2	Year 3	Year 4	Year 5
Kwilu	11 500	106 380	290 570	391 380	291 470
Kasaï	6 329	58 549	159 924	215 407	160 419
Kasaï Central	7 934	73 394	200 471	270 023	201 092
Nord Kivu	8 408	77 778	212 446	286 152	213 104
Total	34 172	316 102	863 411	1 162 962	866 086

Table 7: Exptected number of insured, by province
Source: Client

Each farmer can only receive one payout in the two years of participation in the scheme. Therefore, a farmer who receives a payout in his first year of coverage is excluded from the scheme for the second year.

The goal of the insurance is to protect farmers against low frequency / high severity drought events. The payout will likely have the format of cash/voucher[5]. It is therefore logistically easier to choose a binary payout with a fixed amount.

Parametric insurance differs from traditional insurance in that the payout does not corresponds to the actual loss, but is calculated using an index that is trusted to accurately reflect the insured's loss. This means that there is almost an infinite number of possibilities to create a parametric cover. The two following subsections focus on the definition of the Parametric Designs 1 and 2. The goal is to compare covers in order to optimize net benefits for farmers, each product exploring a different index and different characteristics (payout granularity, threshold granularity, limit). Comparing the two products provides insight into the advantages and disadvantages of each, which helps determine what the optimal cover might be.

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[5] Source : Client

b. Parametric Design 1

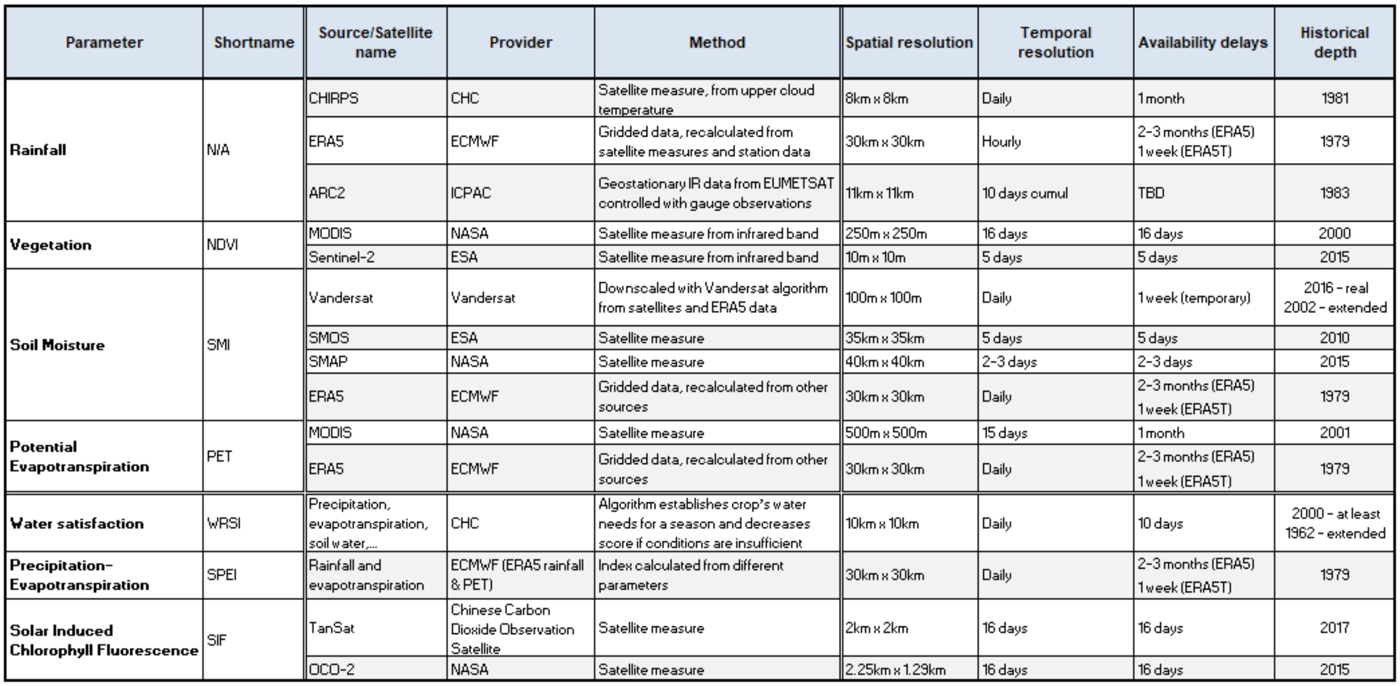
Parametric Design 1 is the one developed in the prefeasibility study. The index is the **SPEI** (*Standardized Precipitation Evapotranspiration Index*), a standardized index based on water balance. The water balance is calculated for each day and territory by aggregating rainfall, minus the evapotranspiration. The daily water balance is then cumulated during the crop development period. This provides a timeseries for each crop and territory. The SPEI index is built by standardizing each timeseries (*i.e.* historical detrending, averaging at zero and standard deviation of one). This allows for comparisons across territories and crops and a common payout structure for all.

Index is based exclusively on ERA5 and ERA5T data, which means that the index can be available very shortly after the end of the risk period (approximately one week). From that point on, the parametric cover can pay for the loss within days.

The payout structure chosen for the Parametric Design 1 is a binary payout. A unique trigger threshold will be calculated as to reach a targeted insurance premium cost of $20 million – the budget allocated by the Client for the risk-transfer instrument. For each territory and each crop, if the index crosses the threshold, a full payout per *crop x territory* will be released. There is one index threshold and limit per farmer regardless of the territory or crop, targeted to be roughly $100 by farmer.

c. Parametric Design 2

To select Parametric Design 2 index, we have established a table gathering information about the main parameters used to detect agricultural drought (Table 8):



Parameter	Shortname	Source/Satellite name	Provider	Method	Spatial resolution	Temporal resolution	Availability delays	Historical depth
Rainfall	N/A	CHIRPS	CHC	Satellite measure, from upper cloud temperature	8km x 8km	Daily	1 month	1981
		ERA5	ECMWF	Gridded data, recalculated from satellite measures and station data	30km x 30km	Hourly	2-3 months (ERA5) 1 week (ERA5T)	1979
		ARC2	ICPAC	Geostationary IR data from EUMETSAT controlled with gauge observations	11km x 11km	10 days cumul	TBD	1983
Vegetation	NDVI	MODIS	NASA	Satellite measure from infrared band	250m x 250m	16 days	16 days	2000
		Sentinel-2	ESA	Satellite measure from infrared band	10m x 10m	5 days	5 days	2015
Soil Moisture	SMI	Vandersat	Vandersat	Downscaled with Vandersat algorithm from satellites and ERA5 data	100m x 100m	Daily	1 week (temporary)	2016 - real 2002 - extended
		SMOS	ESA	Satellite measure	35km x 35km	5 days	5 days	2010
		SMAP	NASA	Satellite measure	40km x 40km	2-3 days	2-3 days	2015
		ERA5	ECMWF	Gridded data, recalculated from other sources	30km x 30km	Daily	2-3 months (ERA5) 1 week (ERA5T)	1979
Potential Evapotranspiration	PET	MODIS	NASA	Satellite measure	500m x 500m	15 days	1 month	2001
		ERA5	ECMWF	Gridded data, recalculated from other sources	30km x 30km	Daily	2-3 months (ERA5) 1 week (ERA5T)	1979
Water satisfaction	WRSI	Precipitation, evapotranspiration, soil water,...	CHC	Algorithm establishes crop's water needs for a season and decreases score if conditions are insufficient	10km x 10km	Daily	10 days	2000 - at least 1962 - extended
Precipitation-Evapotranspiration	SPEI	Rainfall and evapotranspiration	ECMWF (ERA5 rainfall & PET)	Index calculated from different parameters	30km x 30km	Daily	2-3 months (ERA5) 1 week (ERA5T)	1979
Solar Induced Chlorophyll Fluorescence	SIF	TanSat	Chinese Carbon Dioxide Observation Satellite	Satellite measure	2km x 2km	16 days	16 days	2017
		OCO-2	NASA	Satellite measure	2.25km x 1.29km	16 days	16 days	2015

Table 8: Usual weather parameters for agricultural drought
<u>Source</u>*: AXA Climate and official sources*

This table is divided in two: the upper lines (Rainfall, NDVI, Soil Moisture and Potential Evapotranspiration) are parameters that are rather "simple" and straightforward. The last three lines (WRSI, SPEI, SIF) are more complex parameters. We dived into each parameter to evaluate which one can be used for Parametric Design 2:

- **Rainfall**: rainfall alone does not adequately account for yield variations, all the more so in a tropical country. It is however a good starting point, as it is notably used to compute the SPEI index;
- **Vegetation**: The *Normalized Difference Vegetation Index* (NDVI) enables to estimate plant health, by quantifying the amount of live green vegetation in the observed area. A classical way to use this parameter is to compute a timeseries of the NDVI for a given zone, where the same crop has been cultivated for the past years. A climatology of the timeseries is computed, and the index is the deficit of vegetation around the time of the expected maximum of NDVI (just before harvesting). This enables to tell whether the crops were healthy just before harvesting, which gives a decent estimation of yield. In the DRC context however, it is impossible to tell which crop is cultivated and when. It is biased by dense vegetation, and by the fact that different crops are cultivated with different development periods;
- **Soil moisture**: this parameter is interesting because it detects the cause of the drought rather than the consequence (as the NDVI does). It is also more accurate than precipitation alone, as it gives the volume of water effectively present in a given layer of ground. Soil moisture is also slightly biased with dense vegetation, however ERA5 historical data give a consistent seasonal fluctuation (unlike the NDVI).
- **Potential evapotranspiration**: this parameter is a measure of the extent to which near-surface atmospheric conditions are conductive to the process of evaporation. Just like precipitation, this parameter alone does not provide conclusive information. It is however used to compute the SPEI.
- **Water satisfaction**: the *Water Requirement Satisfaction Index* of the African Risk Capacity estimates, on a score from 100 to 0, the water satisfaction of the crop during the season. Crop water requirement is calculated before the sowing based on the crop, the sowing date, depth, irrigation, depth, etc. The initial index value is 100, and it is updated daily based on precipitation. If the crop is under hydric stress, the index is decreased. Once it reaches 0, it remains at that value. This index has proven to be effective, yet our discussions with ARC have shown that the WRSI may not be suitable for our context, due to the lack of input data.
- **SPEI**: the SPEI is a robust drought index, used for Parametric Design 1. It uses an aggregated and standardized water balance (precipitation minus evaporation).
- **SIF**: Solar-induced chlorophyll fluorescence (SIF) provides a new and direct way to monitor photosynthetic activity. Because these data are fairly recent, they are difficult to obtain and it is very complicated to price a parametric cover from them.

To recap, soil moisture appears to be a good alternative to the SPEI used in Parametric Design 1. For simplicity and historical depth, ERA5 seems a good data provider. ECMWF Soil Moisture has shown to be reliable (*cf.* ALBERGEL et AL. [2012]). Although few studies focus on the correlation between soil moisture and crop yield, soil moisture appears to satisfactorily explain crop yield (*cf.* POTOPOVÁ et AL. [2010]). Other studies show that soil moisture index correctly predicts plant health (*cf.* ZRIBI et AL. [2010]). Our experience also indicates that soil moisture can be a good proxy for yield. Moreover, the ERA5T data enables to calculate the payout, if any, a week after the end of the risk period, which is a key advantage for the efficiency of the cover for the farmers.

The selected parameter for Parametric Design 2 is ERA5 soil moisture layer 1 (*i.e.* soil layer at a depth of 0-7cm). Although maize roots can go as deep as one meter, there are good reasons for studying the higher soil layer:

- Going deeper than 40cm does not increase accuracy of the soil moisture index most the time. The intertwined reasons for this is that there is usually a plough-pan (hardpan) formed at roughly 40cm depth, causing the roots to concentrate mainly in the first 40cm of the soil,
- Only two layers remain above this 40cm threshold (0-7cm and 8-28cm). We chose the first one because from testing in other countries, it appears to offer a slightly better correlation with maize yield.
- There is an important correlation between the two first layers of soil moisture, there is no real gain of information by going deeper.

Appendix 1 demonstrates the last two points above, with a particular example.

The cover index (SMI: *Soil Moisture Index*) is then derived from soil moisture and corresponds to the negative anomaly between daily soil moisture and climatology. In other terms, the index is not soil moisture level itself, but the daily negative anomaly cumulated during the growing period of the crop. The SMI has a positive value which increases as the drought worsens (see illustrative Figure 9).

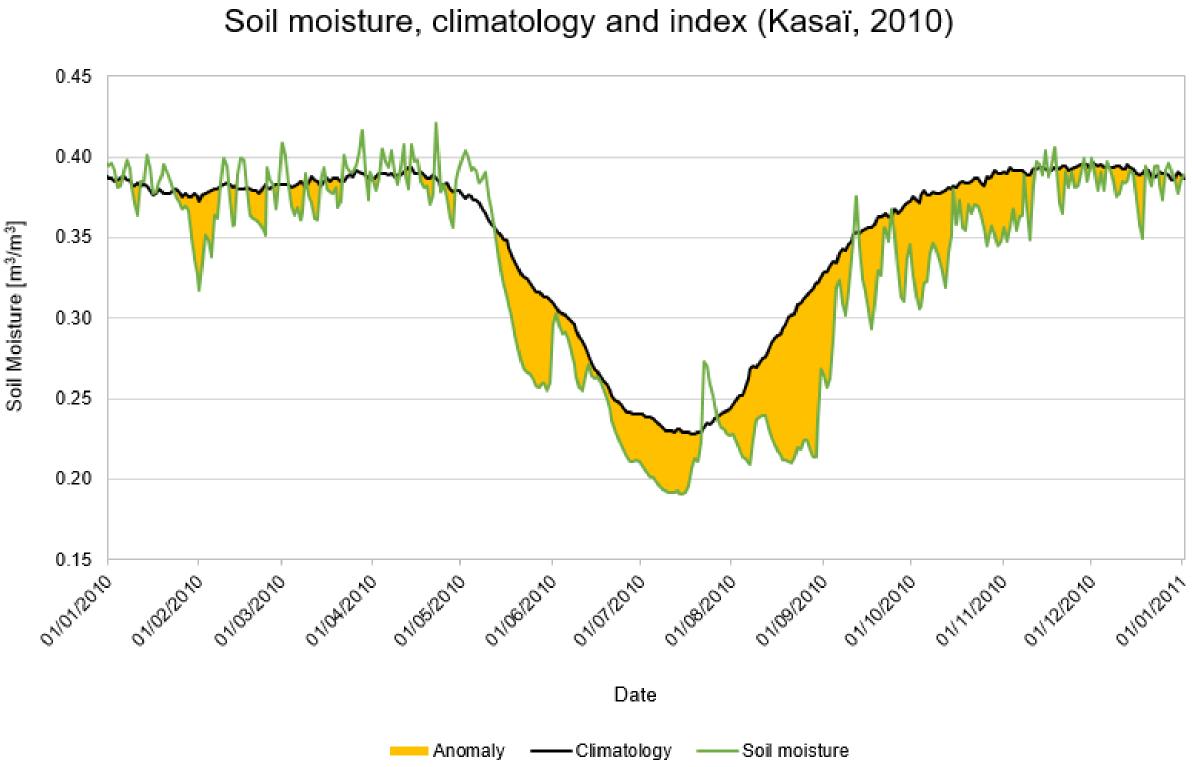
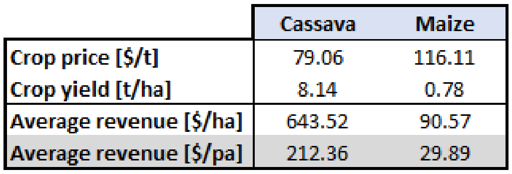


Figure 9: Soil Moisture Index (SMI) calculation, Kasaï 2010
<u>Source</u>: AXA Climate

The spatial accuracy of ERA5 data is 30km by 30km, which makes unrobust the index estimation when only one pixel is considered. This is the case for various small territories (Goma, Kikwit, Tshikapa for instance). To have a more robust index, it is possible to consider a trigger at province level instead of territory level. Since this increases basis risk and brings less diversification, it can be interesting to consider separated limit by crop, and one trigger for each *crop x province*.

The trigger thresholds will be determined as to reach $20 million over five years. The limit by crop, however, is estimated based on the marginal impact of different crops on revenue (see Table 9 below):



	Cassava	Maize
Crop price [$/t]	79.06	116.11
Crop yield [t/ha]	8.14	0.78
Average revenue [$/ha]	643.52	90.57
Average revenue [$/pa]	212.36	29.89

Table 9: National average revenue [$/ha and pa] for cassava and maize in DRC
<u>Source</u>: Prefeasibility study

This Table shows that, assuming that the average prices for maize and cassava are in the good order of magnitude, it is not consistent to set a similar payout for cassava and maize. Since the Client indicates they expect a $80-$100 per farmer cover (*i.e.* roughly $240-$300 per hectare), we selected insured values that were close enough to these amounts while reflecting crop price as shown in Table 9. We conducted further optimization work to see the impact of limit by crop variation on the net benefits of the cover (see Appendix 2). A possible consensual set of values could be: 250$/ha for cassava and 150$/ha for maize (*i.e.* $82.5/farmer for cassva and $49.5/farmer for maize).

The ideal solution, however, would be an **area yield index**. This type of index is only based on the crop yield for the covered area, and payouts are calculated based on deviation from the observed yield to the average expected yield. Such an index would have a close to null basis risk. The remaining basis risk would only be due to spatial aggregation, because deviation would be calcualted for a whole province or territory but could vary in reality from one farmer to the other. However, building such an index requires to have good yield historical records at province (or territory) granularity, which unfortunately does not exist yet in DRC. This is also applicable for indemnity insurance, as detailed below.

What about indemnity insurance?

Indemnity insurance, while initially envisaged as an option, has been **quickly excluded from the scope of the study**. Unlike parametric insurance, which is based on an a priori estimate of the damage thanks to the construction of a correlation between weather data and historical harvests, indemnity insurance corresponds to a more classic approach to insurance where losses are estimated post damage. This means that the payout is conditioned to a visual assessment of the damage by experts sent on site.

While this method may seem more reliable at first glance, we do not believe it is advisable to implement it in the case of the project for several reasons:

- First, based on available information, no insurer in the Democratic Republic of Congo offers an agricultural indemnity insurance product. It is therefore **not possible to rely on experimented local resources** to carry out crop cutting experiments and on-site damage assessments;
- Second, experience of agricultural indemnity insurance programs around the world shows the need of specific procedures and dedicated/trained resources for proper financial management of such schemes and for damage assessment.
- Moreover, in the absence of historical yield data, it is **impossible to give a reliable price** to indemnity insurance. This problem can also apply to parametric insurance, but it has been circumvented by constructing a product where the payout is triggered according to thresholds crossed by ERA5 satellite data, regardless of their actual link with the yield. This solution implies a basis risk but nevertheless allows for robust pricing and thus guarantees the appetite of (re)insurers.
- Finally, the complexity of operational implementation of indemnity insurance would lead to **late payments**. By way of comparison, in the Indian PMFBY program, payments can take up to two years to be made, and this timeframe could be longer in DRC given the lack of experience. In contrast, parametric insurance payouts can be made in a matter of days.

2. Reserve fund

a. General information

The general reserve fund of the program contains $20 million and is dedicated to all sorts of perils. The hypothesis discussed with the Client is that $10 million can be dedicated to weather events.

The value of the indemnity per farmer is targeted to be $30. However, this amount is indicative and could vary according to the realities in the field during emergency response and / or in the light of pre-agreed contingency plans.

The payout structure chosen for the reserve is a binary payout. The threshold has been discussed with Client in order to give satisfactory protection to farmers against frequent events. For each territory and each crop, if the index crosses the attachment point, a full payout will be released. An exit point was also added, beyond which no payout is triggered by the reserve, to ensure that it focuses on high frequency / low severity events only.

Since farmers cannot be excluded from the scheme in practice, exposure soars as years go by. To avoid having too much exposure during last year, we have discussed with Client a rule which states that each farmer can get a payout twice, at maximum, over the five years.

Finally, after discussions with Client, we propose to study an alternative scheme where the reserve buys insurance for itself. We target a *c.a.* $2m insurance premium, to buy an 8XL8 non proportional insurance. The idea is that the insurance covers the aggregated loss of the reserve, when it is exhausted (*i.e.* after $8 million losses) with a maximum $8 million capacity (in other words, once empty, the reserve can be filled again by insurance). This creates a protection with a maximum $16 million capacity. This set-up will be named "**Insured Reserve**" hereafter, while the initial reserve will be named "**Standalone Reserve**".

b. Soft trigger

Admittedly, the main limitation of parametric insurance is basis risk, *i.e.* the risk that a fall in farmers' yield is not reflected in the chosen weather index and therefore does not lead to financial compensation. To protect farmers in case of extreme rainfall or drought not captured by the index, we propose to introduce a soft trigger to the global covering scheme. The idea of a soft trigger is no longer to compensate farmers on the basis of a quantitative meteorological index, but on the basis of humanitarian alerts relayed by associations on the ground.

We suggest that the reserve is activated by soft trigger according to the following modalities:

- In case of an humanitarian situation requiring urgent help, local associations on the ground alert the Client;
- The Client, together with the Government, decide to activate the soft trigger, with a limited payout capacity for each activation (*e.g.* $300,000 – to be determined by the Client);
- Simulteanously, the parametric index is monitored. If the threshold corresponding to 1 in 5 return period is crossed, the payout is amplified up to an average of $30 per farmer in the affected regions.

In terms of operational modalities to set up this soft trigger, many avenues can be explored as it is a rather innovative solution. Initial discussions have been engaged with an association specialized in the financing and operational management of climate risks. It is internationally recognized, has a strong footprint in Africa and works in close collaboration with several international donors and (re)insurers. This association has a network of partner associations in the DRC that could monitor the situation of the farmers and alert the Client and the government in case of famine or other emergency situation. The association could thus play an early warning role, relaying ground information to the DRC Government and to the Client which would then co-decide to activate or not the soft trigger. If activated, the payment would be made to farmers either based on existing procedures or, if deemed relevant by the Client, by leveraging the association capabilities on the ground.

The mechanism of the soft trigger is summarized in the figure below.

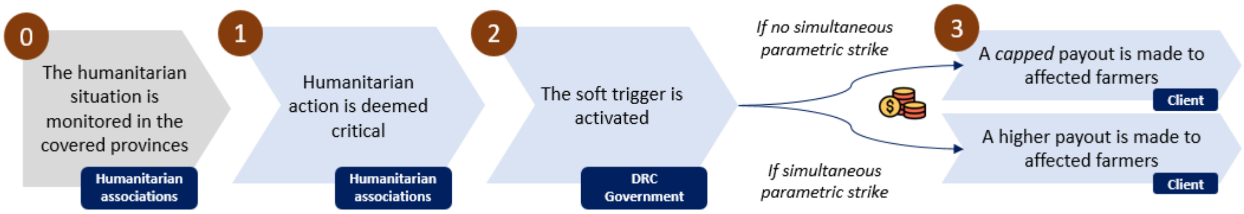


Figure 10: “Soft” trigger emergency option illustration
Source: AXA Climate. For illustrative purposes only.

3. Hybrid structure

The goal is to create a multilayer cover for farmers. The $10 million reserve dedicated to index events can be the first layer, which protects against high frequency / low severity events, while parametric insurance covers against low frequency / high severity events. In order to have a layered cover, the reserve dedicated to parametric index events must be triggered based on the same index as the parametric insurance. The whole cover created is then called “Hybrid” as it gathers two different instruments (reserve fund and parametric insurance). Since there are two different parametric designs, there will be at least two hybrid structures to be compared.

Figure 11 shows a schematic recapitulative view of the Hybrid structure. The general reserve fund of the program contains $20 million and is dedicated to all sorts of perils. The hypothesis discussed with the Client is that we can dedicate $10 million to parametric index events (Components B), while leaving the rest to remaining perils (Component A). The goal behind this hypothesis is to optimize the parametric cover by adding a layer to the parametric insurance scheme (Component C). The reserve can be the first layer, which protects against high frequency / low severity events.

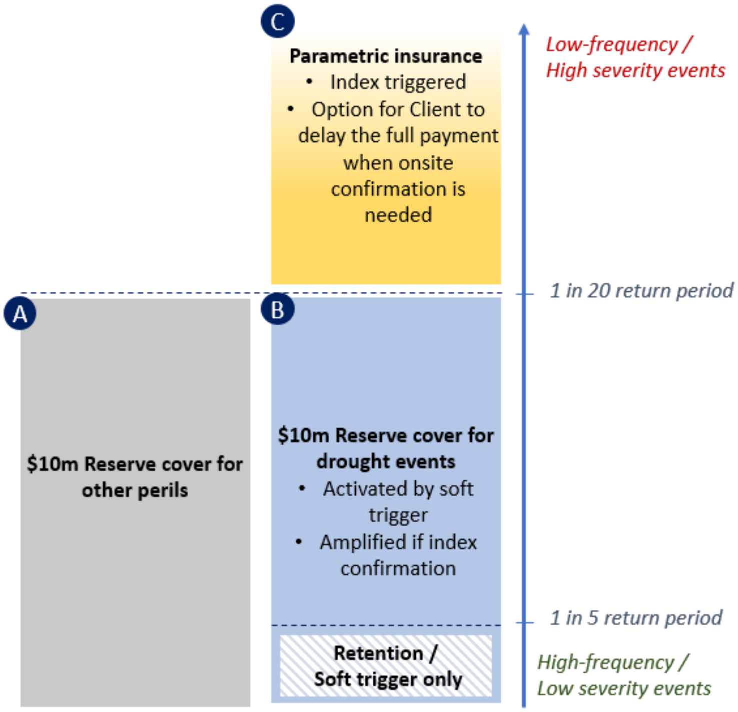


Figure 11: Illustrive hybrid set up (Reserve and Parametric Insurance)
Source: AXA Climate. For illustrative purposes only

3 – COVER STRUCTURING

This section focuses on cover structuring, *i.e.* determining the details of covers for parametric insurance and reserve. The first subsection quickly describes yield and index modelling, as it is a necessary first step in order to be able to price the covers. The second subsection focuses on parametric insurance, in particular on the trigger threshold to chose in order to ensure the cover does not exceed $20 million premium over the five years. Finally, the third subsection shows how to select reasonable settings for reserve (indemnity per person, number of payouts per person, attachment and exit point).

1. Modelling

a. Litterature review

Modelling and pricing of parametric insurance has been very studied lately, through articles that treat the question quite extensively, in particular in the field of agriculture insurance. CÔME [2018] details how to build and price an insurance cover for maize in Mali, using two parameters: temperature and NDVI. AOUN [2018] also uses NDVI index for parametric insurance, which he uses to build cover in north-est France. KOULI [2018] shows how to create, calibrate and price a cover based on a yield-predicting model in Morocco, while KOCH [2011] looks for the best combination of index to replicate and protect sugar yield in Morocco. He uses five main parameters to try and estimate yield: temperature anomalies, maximal and minimal temperature, precipitation and growing degree days. His work shows that the best model achieves only a 31% correlation with sugar yield. This highlights the difficulty to estimate yield from only climatic parameters based on temperature and precipitation alone. PIETTE [2015] studies and compares pricing of yield and NDVI parametric insurance for the US, and BOUTON [2017] studies how to build and price parametric yield insurance and the inclusion of commodity price in the structure (quanto covers).

These works are the ones focusing on pricing of parametric insurance dedicated to agriculture, however there are numerous other studies around parametric insurance, how to build a cover and price it. For instance, DIVARDJIAN et NOVAKOVIC [2013] show how CCRIF cover works, protecting a wide range of Caribbean countries against both earthquake and tropical cyclones. In the same area, but different peril, RITLENG et NGUYEN [2014] study the calibration and pricing of an excess of rain index covering whole Jamaica. Back to France, several articles deal with wind parametric covers, focusing on different sensitivities though. For instance, SADOU [2017] explores in parallel wind and solar covers for renewable energy, while FINAS et GILLES [2011] study parametric wind covers for windarm, exploring various structure derived from climate derivatives (put, collar, swap). Finally, VENDÉ [2003] looks at a windstorm cover and shows great attention to correlation across the whole country.

Since all these aspects of modelling, fitting and pricing have been already very detailed in precedent works, and since this report is focusing on the Cost-Benefit Analysis rather than on the modelling and pricing, it seems logical not reinvent the wheel and to be very concise on the modelling and pricing of the parametric insurance.

b. *Yield modelling*

As explained in section **1.3.a.**, the yield we use is prefeasibility historical yield built from SPEI alone. For the sake of illustration, it is possible to display an example of one timeseries as it was given (see Figure 12 below):

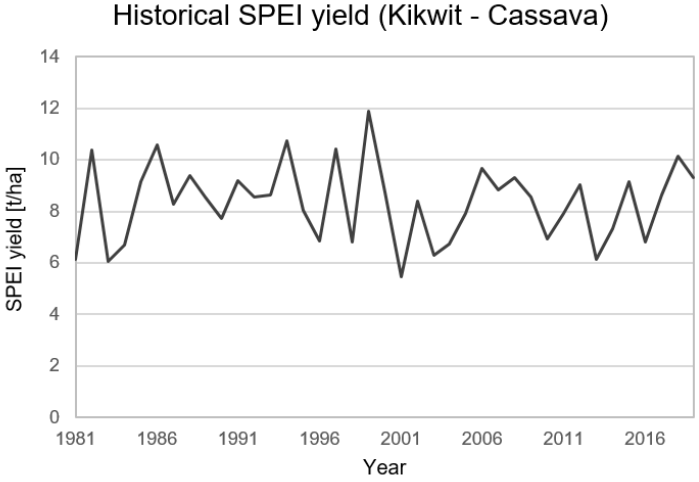


Figure 12: Historical SPEI Yield [t/ha] for Cassava in Kikwit territory, 1981-2019
Source: Prefeasibility study

As Figure 12 shows, there is no obvious trend to be considered and thus no detrending has been applied to the series. This is consistent with what is expected of yields in a developing country such as DRC. From this series is is then possible to move on to the fitting.

Yields tend to be quite well modelled by Gamma distributions. This is all the more true for low yields, as maize yields in this case (less than 1 t/ha). Since this historical dataset is modelled from an index (SPEI) and since there is no estimate what so ever of the error realized with this estimate – because there is no proper yield records in DRC that have been made available, it seems even more reasonable to choose a simple distribution to model our yield. This is why we decided to model yields with Gamma distribution, which fits quite well with data available (see Figure 13).

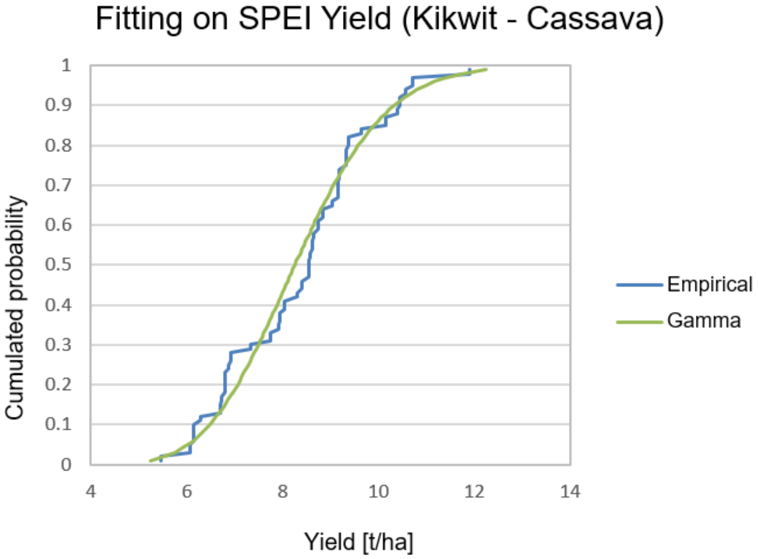


Figure 13: SPEI Yield fitting for Cassava in Kikwit territory with Gamma distribution ($\alpha = 30.56, \beta = 0.27$)
Source: AXA Climate

c. Index modelling

This subsection focuses on SPEI modelling, because it is interesting to clarify how it was derived from the yields, since prefeasibility SPEI was not directly made available. The fitting applied is done with the exact same method for the SMI. This part hence does not describe both and only details how SPEI modelling was carried out.

Prefeasibility study explains that SPEI was used to create historical yield variability around its average value. We do not have access to prefeasibility study SPEI index, but we do have the historical yields they used. We also know the index is normalized for each crop and territory. From there, the SPEI historical values for a given crop *x* territory can be calculated by normalizing the historical yield:

$$SPEI_t^{territory} = \frac{Yield_t^{territory} - E[Yield^{territory}]}{\sqrt{V[Yield^{territory}]}}$$

The index is thus directly the noise of the yield we saw previously, hence the similarities between the two series (see Figure 14 below):

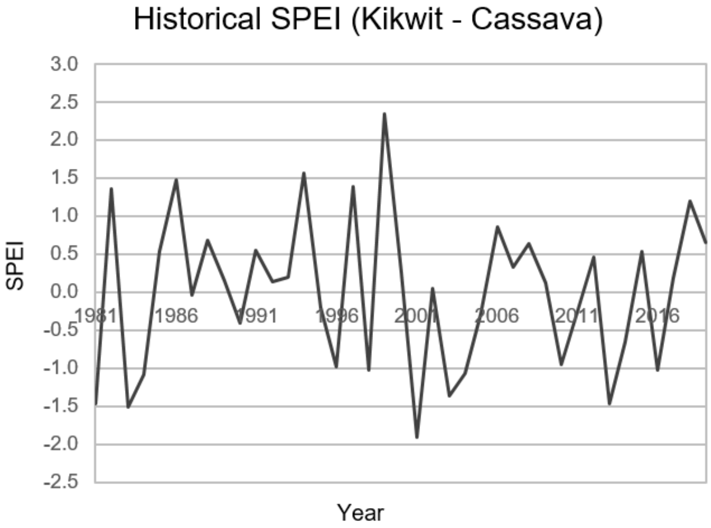


Figure 14: Historical SPEI for Cassava in Kikwit territory, 1981-2019
Source: Prefeasibility study

It would be logical to use the same distribution as for the yields, however Gamma distribution only exists for positive values. As shown in Figure 14 above, the SPEI can be negative. The simplest way to model such a series is then a normal distribution (see fitting Figure 15 below):

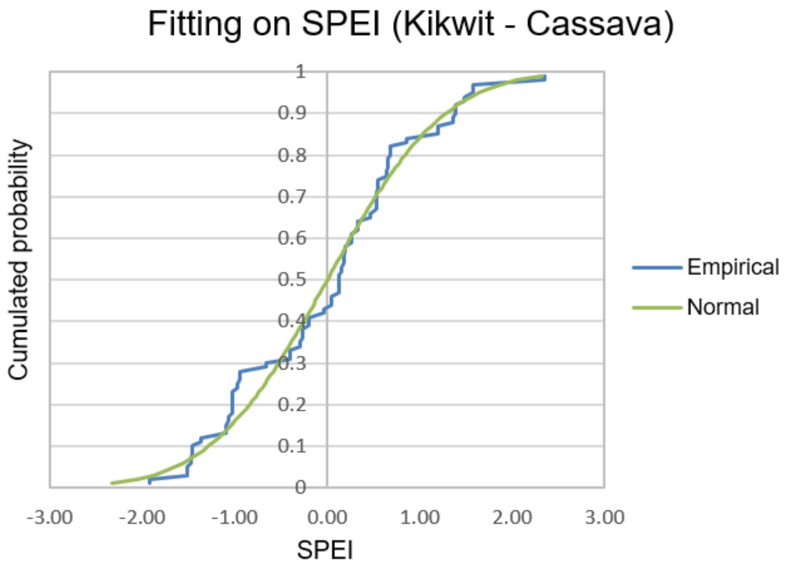


Figure 15: SPEI fitting for Cassava in Kikwit territory with Normal distribution (μ=0,σ=1)
Source: AXA Climate

The same fitting method is applied to SMI, once put in as-if to serve pricing purposes. Since SMI have lower values and are strictly positive though, Gamma distributions are a more reliable choice to model them.

d. Correlations

Once yields and index are properly modelled, it is important to study the correlation that exist between yields and index. This is of no use to the pure parametric insurance and reserve pricing, however it will be essential to have consistent results in the CBA.

The summarized steps we took so far are as follows:

- **Yield**: we use as-if historical yield, based solely on SPEI, to fit gamma distributions (one for each *crop x territory*);
- **Index** :
  - SPEI: we build back the index by normalizing the as-if historical yield, and then model it with normal distributions;
  - SMI: we use historical data to model the SMI with gamma distributions;

We can now focus on correlations:

- **Correlation**:
  - Yield: we use the as-if historical yield to build a correlation matrix;
  - SPEI: the correlation matrix is the same as for yield, since yield are directly estimated from SPEI. The correlation matrix is displayed below (Figure 16):

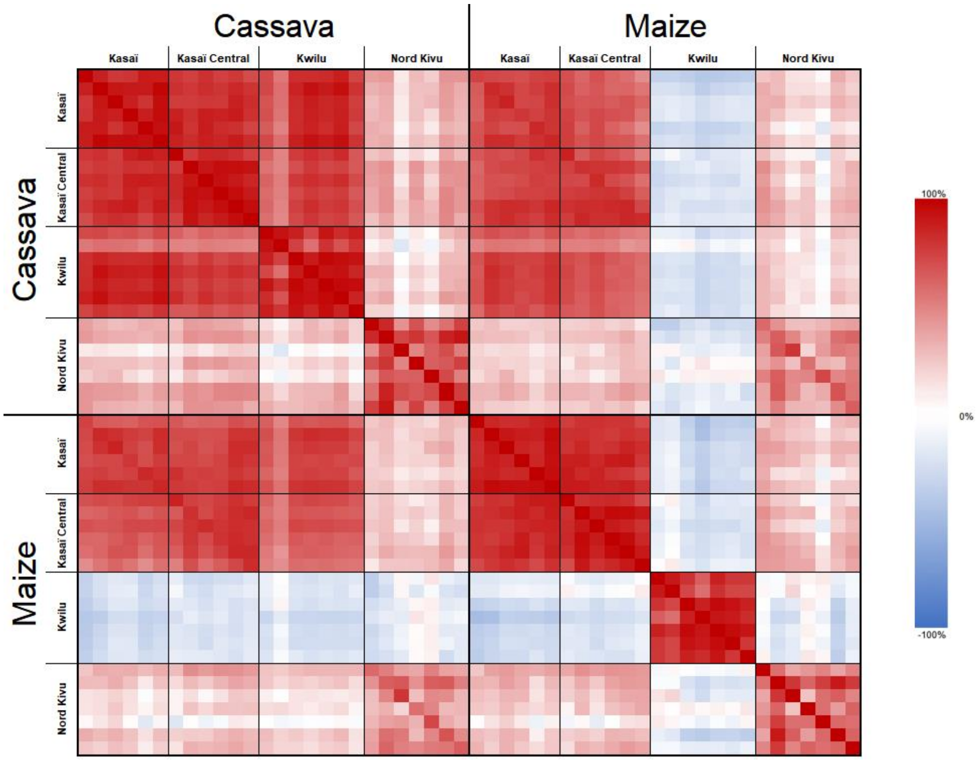


Figure 16: SPEI empirical correlation matrix based on historical data (*crop x territory*)
<u>Source</u>: *prefeasibility study*

- SMI: the correlation matrix was directly derived from historical data, and is calculated at *crop x province* level to be consistent with the index granularity (see Figure 17 below):

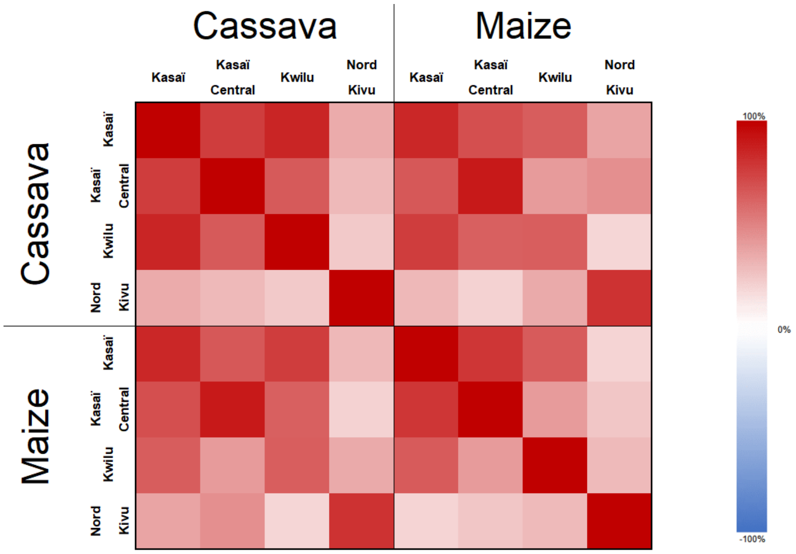


Figure 17: SMI empirical correlation matrix based on historical data (*crop x province*)
<u>Source</u>: *AXA Climate*

- Correlation between index and yield: this correlation cannot be calculated due to lack of yield data. We assumed the underlying correlation dynamics was the same that the inner correlation of the index.

Some comments can be made on these correlation matrix. The first thing is that there is always a significant positive correlation in the same province (Figure 16), which seems logical. Moreover, Kwilu is neigbouring province with Kasaï and Kasaï Central, so we do expect a significant positive correlation between these provinces, as the figure indeed show. It appears that Nord Kivu has a lower correlation with other provinces (in both figures), which makes sense given it is quite remote from the other three provinces.
The main difference between Figure 16 and Figure 17 is the anticorrelation between maize in Kwilu and the rest of the crops the appears in Figure 16. There is no clear nor logical explanation for this phenomenon, all the more that it does not exist on the SMI at province level.

Once all marginal distributions have been fitted, it is possible to simulate correlated sets of yield and index (SPEI and SMI), using the above mentioned matrix and Gaussian copula. This is a quite strong hypothesis. Although it seems only logical to assume underlying gaussian copula for index/index correlation and yield/yield correlation, it does not strike as obvious for index/yield correlation. Indeed, a simple reasoning can show that we exptect bad yields when a severe drought occurs, however we cannot say much on yields if there is no drought: they could be good or bad (due to another peril, be it excess of rainfall or pest). Appendix 1 (and in particular Figure 40) shows this intuition seems correct. Lack of time and difficulty to model two copulas (Gaussian and, say, Clayton) from a unique correlation matrix makes that we consider only Gaussian copula for all variables.

These simulations are used to price parametric insurance, estimate the drawdown of the reserve, and calculate the cost-benefit analysis. For the modelling and the pricing, a “Base Case” scenario has been adopted. This means there is no projection for climate change taken into account, *i.e.* the average of the index remains the same over the next five years. This hypothesis will be relaxed in sensitivity analysis, where climate change will be taken into account under different scenarios.

2. Parametric insurance

This subsection focuses on the pricing of the two parametric products (based respectively on SPEI and SMI). It is important to highlight two hypothesis. The first one is that no projection for climate change has been taken into account for the pricing, *i.e.* the average of the index remains the same over the next five years. The second hypothesis is that the premium equals two times the *Expected Loss*, which is the average loss that the cover is expected to cost to the insurer. This is a rather conservative estimation, based on the hypothesis of a 40% margin ratio applied to the expected loss, with 20% administrative costs charged by local insurer and 15% brokering costs.

a. Parametric Design 1 (SPEI)

As described in previous section, Parametric Design 1 is based on a binary payout, with a fixed limit for all crops and territories - $99/farmer targeted – and a common trigger threshold for all. The goal of this part is to find the right threshold in order to ensure that the cover premium will not cost more than $20 million over the five years of the scheme.

The payout structure of the Parametric Design 1 is as follows (Figure 18):

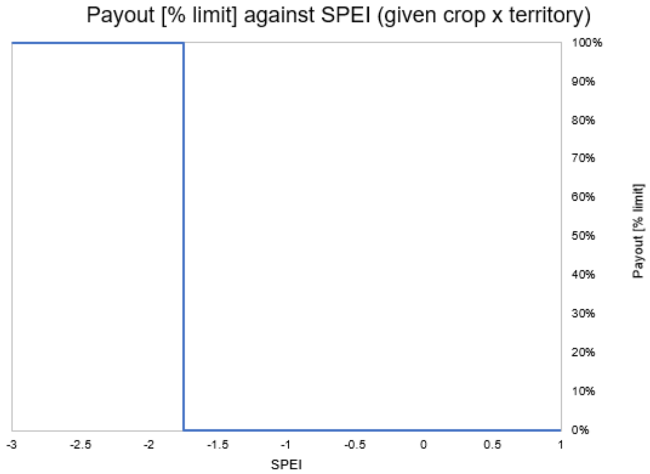


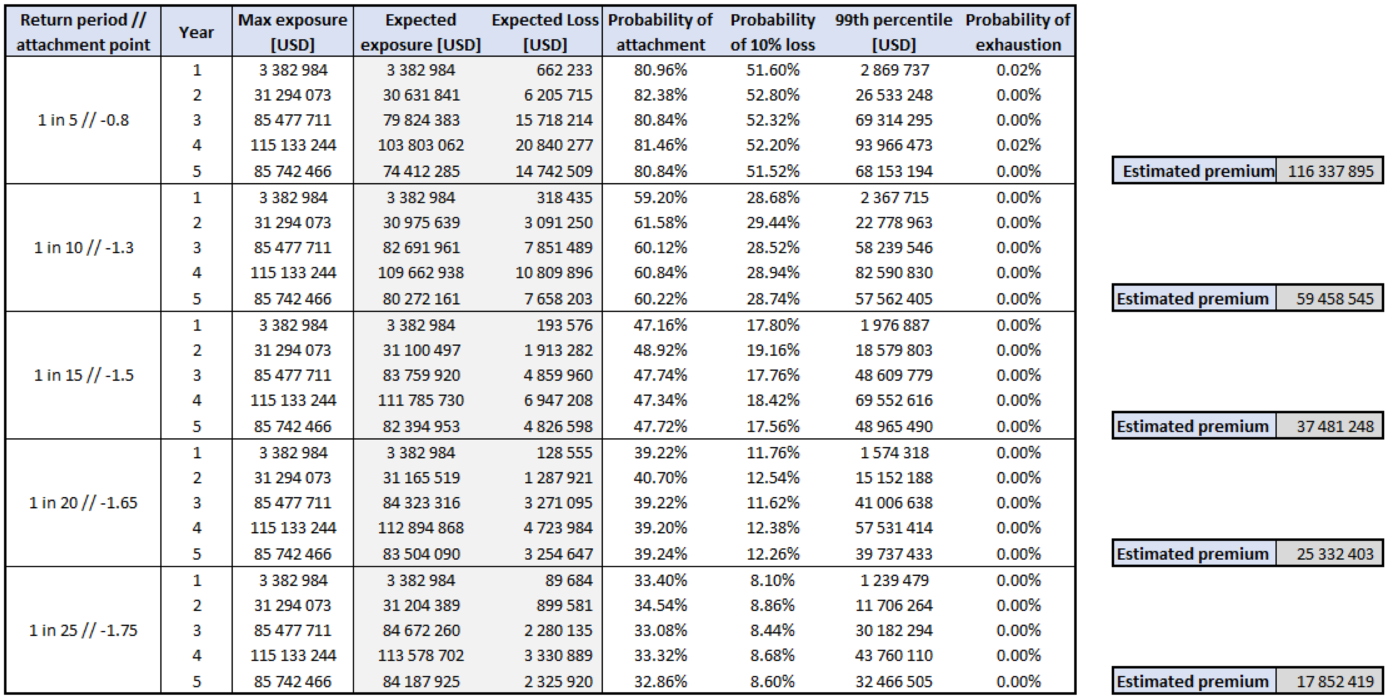
Figure 18: Payout structure of Parametric Design 1 (given *crop x territory*), illustrative trigger at -1.75
Source: AXA Climate

The SPEI shows a drought when its value becomes small/negative. That is why the payout is 100% of the limit (for a given *crop x territory*) if the SPEI is smaller than the threshold. In Figure 18, the illustrative threshold is set at -1.75, which corresponds to an average 25 return period drought. This is true under the hypothesis that SPEI follows a normal distribution, and that risks are homogenenous between territories.

We have priced this cover for triggers at different return periods (5, 10, 15, 20 and 25 years). The goal is to find a trigger which corresponds to a 20 year return period event. The different metrics we use in order to give some insight on the characteristics of the cover are the following:

- Maximum exposure [USD]: maximum limit of the cover for a given year. This is the limit – $99 per farmer – multiplied by the number of insured farmers in each year (see Table 7).
- Expected exposure [USD]: this value reflects the impact of the hypothesis that farmers indemnified during their first year of coverage are excluding from the scheme. This causes potential decrease of exposure. The higher the threshold, the more payouts there are, the lower this exposure will be as years goes by.
- Expected Loss [USD]: average yearly aggregated payout from cover.
- Probability of attachment: probability to trigger the cover, *i.e.* that payout exceeds zero.
- Probability of 10% loss: probability that payout exceeds 10% of limit.
- 99th percentile [USD]: payout with a hundred years return period.
- Probability of exhaustion: probability that the payout reaches the full limit.

The following metrics are gathered for Parametric Design 1 (SPEI) in Table 10 below.



Return period // attachment point	Year	Max exposure [USD]	Expected exposure [USD]	Expected Loss [USD]	Probability of attachment	Probability of 10% loss	99th percentile [USD]	Probability of exhaustion		
1 in 5 // -0.8	1	3 382 984	3 382 984	662 233	80.96%	51.60%	2 869 737	0.02%		
	2	31 294 073	30 631 841	6 205 715	82.38%	52.80%	26 533 248	0.00%		
	3	85 477 711	79 824 383	15 718 214	80.84%	52.32%	69 314 295	0.00%		
	4	115 133 244	103 803 062	20 840 277	81.46%	52.20%	93 966 473	0.02%		
	5	85 742 466	74 412 285	14 742 509	80.84%	51.52%	68 153 194	0.00%	**Estimated premium**	116 337 895
1 in 10 // -1.3	1	3 382 984	3 382 984	318 435	59.20%	28.68%	2 367 715	0.00%		
	2	31 294 073	30 975 639	3 091 250	61.58%	29.44%	22 778 963	0.00%		
	3	85 477 711	82 691 961	7 851 489	60.12%	28.52%	58 239 546	0.00%		
	4	115 133 244	109 662 938	10 809 896	60.84%	28.94%	82 590 830	0.00%		
	5	85 742 466	80 272 161	7 658 203	60.22%	28.74%	57 562 405	0.00%	**Estimated premium**	59 458 545
1 in 15 // -1.5	1	3 382 984	3 382 984	193 576	47.16%	17.80%	1 976 887	0.00%		
	2	31 294 073	31 100 497	1 913 282	48.92%	19.16%	18 579 803	0.00%		
	3	85 477 711	83 759 920	4 859 960	47.74%	17.76%	48 609 779	0.00%		
	4	115 133 244	111 785 730	6 947 208	47.34%	18.42%	69 552 616	0.00%		
	5	85 742 466	82 394 953	4 826 598	47.72%	17.56%	48 965 490	0.00%	**Estimated premium**	37 481 248
1 in 20 // -1.65	1	3 382 984	3 382 984	128 555	39.22%	11.76%	1 574 318	0.00%		
	2	31 294 073	31 165 519	1 287 921	40.70%	12.54%	15 152 188	0.00%		
	3	85 477 711	84 323 316	3 271 095	39.22%	11.62%	41 006 638	0.00%		
	4	115 133 244	112 894 868	4 723 984	39.20%	12.38%	57 531 414	0.00%		
	5	85 742 466	83 504 090	3 254 647	39.24%	12.26%	39 737 433	0.00%	**Estimated premium**	25 332 403
1 in 25 // -1.75	1	3 382 984	3 382 984	89 684	33.40%	8.10%	1 239 479	0.00%		
	2	31 294 073	31 204 389	899 581	34.54%	8.86%	11 706 264	0.00%		
	3	85 477 711	84 672 260	2 280 135	33.08%	8.44%	30 182 294	0.00%		
	4	115 133 244	113 578 702	3 330 889	33.32%	8.68%	43 760 110	0.00%		
	5	85 742 466	84 187 925	2 325 920	32.86%	8.60%	32 466 505	0.00%	**Estimated premium**	17 852 419

Table 10: Key metrics of Parametric Design 1 for different attachment points, at aggregated level
<u>Source</u>: AXA Climate

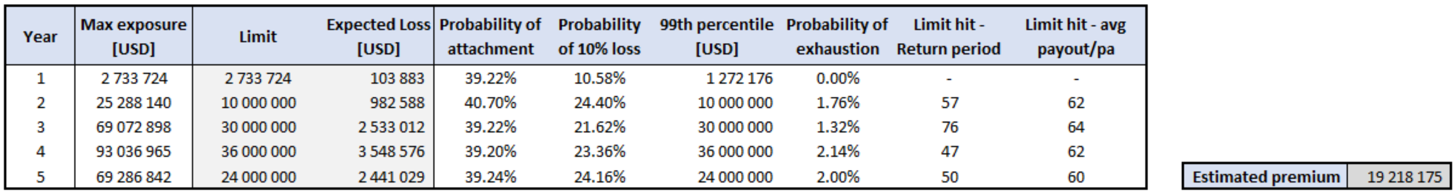
Results in Table 10 show that having a cover per territory and crop provides diversification to the aggregated cover. This is particularly highlighted by the difference between expected exposure and 99th percentile, as well as by the limit hit probability: it is very unlikely that all *crops x territories* trigger at once.

Yet this granularity causes the aggregated cover to trigger very often. Even when the attachment point is set at a return period of 25 years per territory, the nationwide cover has a payout every three years on average.

These numbers show that only the last cover, with attachment set at a 25 year return period, is in line with the $20,000,000 budget. This does not complies with the target to have a 20 year return period. It is however possible to reduce the premium by setting the payout at $80 per person, and introducing an annual aggregate limit, so that final aggregated payout could not exceed the annual limit. This aggregate limit can however decrease the initial payout per farmer. Indeed, if the aggregated loss exceeds the annual limit, the payout per farmer must be decreased in order to cover all farmers.

To ensure that this dilution is not excessive, the following metrics have been calculated:
- Limit: annual aggregate limit, which the cumulated payout cannot exceed.
- Limit hit – return period: gives the return period at which the annual limit is reached.
- Limit hit – avg payout/pa: average payout per farmer in case the limit is reached.

We propose the following structure (see Table 11) as a solution to stick to the 20 year return period.



Year	Max exposure [USD]	Limit	Expected Loss [USD]	Probability of attachment	Probability of 10% loss	99th percentile [USD]	Probability of exhaustion	Limit hit - Return period	Limit hit - avg payout/pa
1	2 733 724	2 733 724	103 883	39.22%	10.58%	1 272 176	0.00%	-	-
2	25 288 140	10 000 000	982 588	40.70%	24.40%	10 000 000	1.76%	57	62
3	69 072 898	30 000 000	2 533 012	39.22%	21.62%	30 000 000	1.32%	76	64
4	93 036 965	36 000 000	3 548 576	39.20%	23.36%	36 000 000	2.14%	47	62
5	69 286 842	24 000 000	2 441 029	39.24%	24.16%	24 000 000	2.00%	50	60

Estimated premium	19 218 175

Table 11: Parametric Design 1 key results ($80/pa limit, trigger at -1.65 *i.e.* 20 year return period)
Source: *AXA Climate*

Maximum exposure decreases as payouts goes from $99/farmer to $80/farmer. This cover has an attachment point at -1.65, which corresponds to an average return period of 20 years at *crop x territory* granularity. The limit per farmer has been decreased to $80, and an aggregate limit sets a maximum payout per year (last right column). The probability of exhaustion reaches approximately 2% for final years, however the average payout per farmer in case limit is exceeded stays reasonable (roughly $60/pa).

Note: It might be counterintuitive to observe that the probability of 10% loss increases with the introduction of an Annual Aggregate Limit (AAL). This is explained by the fact that the underlying risk does not change with the introduction of a lower limit. For year 4, for instance, limit is set to $36,000,000 in Table 11 whereas it was actually $115,000,000 without AAL in Table 10 (for the 1 in 20 cover). A 10% loss with AAL amounts to $3,600,000, which is quite frequently reached, compared to $11,500,000 without AAL. With no change in the underlying risk, this mechanically causes the 10% loss probability to increase.

The cover as built requires a $19,218,175 premium over five years, which makes it compliant with the budget. This is the cover that we select for Parametric Design 1.

b. Parametric Design 2 (SMI)

Parametric Design 2 is based on the Soil Moisture Index. The index is calculated at *crop x province* granularity, so is set the threshold. Contrarily to SPEI, the SMI is positive and the higher it gets, the worse is the drought. The payout structure has thus the following shape (Figure 19):

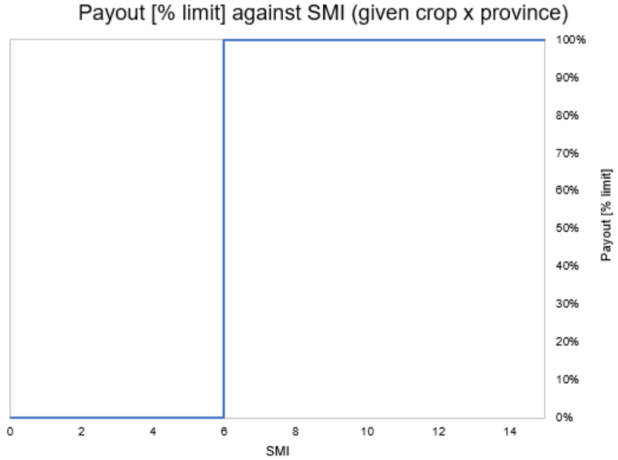


Figure 19: Payout structure of Parametric Design 2 (given *crop x province*), illustrative trigger at 6
Source: *AXA Climate*

A specificity of Parametric Design 2 is that it has a different attachment point for each *crop x province*. Each attachment point is set to correspond to an event with a 20 year return period. Another special feature of Parametric

Design 2 is that the limit has been separated by crop, in order to reflect their marginal contribution to the overall revenue. The chosen limits are $250/ha for cassava (*i.e.* $82.5/farmer) and $150/ha for maize (*i.e.* $49.5/farmer). In other words, since maize contributes less to farmers' income on average because of its lower price, a maize crop loss is compensated less than a cassava crop loss.The same metrics as for Parametric Design 1 have been computed in order to find the optimal attachment point (see results in Table 12 below).

Return period // attachment point	Year	Max exposure [USD]	Expected exposure [USD]	Expected Loss [% limit]	Probability of attachment	Probability of 10% loss	99th percentile [USD]	Probability of exhaustion		
1 in 5	1	2 097 445	2 097 445	424 320	54.37%	44.67%	2 097 445	1.27%		
	2	19 402 281	18 977 961	3 756 708	53.15%	43.57%	18 870 458	1.30%		
	3	52 996 058	49 570 257	10 115 352	53.41%	44.74%	50 114 787	1.38%		
	4	71 382 446	64 120 261	12 906 848	54.48%	45.76%	65 168 139	1.21%		
	5	53 160 206	45 978 539	9 032 591	53.23%	44.63%	48 532 264	0.55%	**Estimated premium**	72 471 640
1 in 10	1	2 097 445	2 097 445	213 027	33.61%	25.52%	1 665 904	0.28%		
	2	19 402 281	19 189 253	1 915 212	32.90%	24.68%	15 175 354	0.25%		
	3	52 996 058	51 268 734	5 344 424	33.70%	25.94%	41 450 485	0.33%		
	4	71 382 446	67 666 998	6 759 540	33.59%	26.12%	53 636 049	0.34%		
	5	53 160 206	49 593 997	4 890 927	32.71%	25.28%	39 944 042	0.06%	**Estimated premium**	38 246 259
1 in 15	1	2 097 445	2 097 445	138 127	23.47%	17.64%	1 550 674	0.07%		
	2	19 402 281	19 264 153	1 246 492	23.50%	17.17%	13 582 249	0.09%		
	3	52 996 058	51 877 050	3 573 454	23.79%	18.02%	39 038 383	0.11%		
	4	71 382 446	68 925 333	4 456 713	24.03%	18.11%	49 970 114	0.17%		
	5	53 160 206	50 856 524	3 226 556	22.93%	17.28%	37 213 933	0.02%	**Estimated premium**	25 282 686
1 in 20	1	2 097 445	2 097 445	103 085	18.83%	13.60%	1 393 403	0.04%		
	2	19 402 281	19 299 196	939 345	19.01%	13.08%	12 889 583	0.02%		
	3	52 996 058	52 154 417	2 665 049	18.85%	13.57%	35 207 051	0.05%		
	4	71 382 446	69 560 558	3 330 598	18.76%	13.58%	47 421 742	0.07%		
	5	53 160 206	51 452 947	2 439 861	18.37%	13.00%	35 316 100	0.01%	**Estimated premium**	18 955 876
1 in 25	1	2 097 445	2 097 445	81 950	15.46%	11.05%	1 224 133	0.03%		
	2	19 402 281	19 320 331	752 709	15.77%	10.81%	11 893 671	0.02%		
	3	52 996 058	52 322 556	2 162 143	15.72%	11.07%	35 207 051	0.04%		
	4	71 382 446	69 908 662	2 643 153	15.25%	10.79%	41 660 956	0.03%		
	5	53 160 206	51 810 332	1 975 233	15.19%	10.68%	31 025 905	0.00%	**Estimated premium**	15 230 377

Table 12: Key metrics of Parametric Design 2 for different attachment points, at aggregated level
Source: AXA Climate

It is interesting to compare the difference of percentile value and limit hit probability between Parametric Design 1 and 2. The first result is that setting up an aggregated index and trigger at province level instead of territory decreases diversification. Indeed, the exhaustion probability (last right column) is above zero, even for the cover with a 25 year return period attachment point. The lack of diversification compared to Parametric Product 1 can also be deduced from the relative closeness between expected exposure and 99th percentile, whereas the gap between the two was wider in Parametric Design 1.

It is however positive to observe that a 20 year return period cover has a 5 year cumulated premium of $18,955,876, smaller than the $20 million maximum. We thus chose this cover for Parametric Design 2.

c. *Recap of results*

The following table (Table 13) summarizes the choices, similarities and differences between Parametric Design 1 and Parametric Design 2.

	Parametric Design 1	Parametric Design 2
Index	SPEI	SMI
Payout granularity	crop x territory	crop x province
Threshold granularity	one for all	crop x province
Attachment point	1 in 20	1 in 20
Limit/farmer	$80	cassava: $82.5 & maize: $49.5
Annual Aggregated Limit	Yes	No
5 year premium	$19,218,715	$18,955,876

Table 13: Recap of main characteristics, Parametric Design 1 and 2
Source: AXA Climate

3. Reserve fund

The idea of the reserve (i.e. the $10 million dedicated to the hard index events) is to protect against high frequency / low severity events. Given the high basis risk of the index for high frequency events, we recommend to rely on soft trigger to activate the reserve fund, with a reasonable payout limit per activation, which is to be defined by the Client (e.g. $300,000).

However, to uncap the payout from the reserve, we believe there is a need for a quantitative confirmation of the event by the index. Our discussions with the Client lead us to consider a trigger for index events with an average five years return period, for a targeted $20/farmer limit. The index and threshold however depend on the Parametric Design considered for the parametric insurance, since the goal is to combine the reserve with the parametric design to create a multilayer cover. It is thus necessary to separate the study between Reserve for Parametric Design 1 and Reserve for Parametric Design 2.

Both analysis also incorporate a modelling of an insured reserve (where the reserve is filled by an insurance payout when empty), although this option is not recommended because of its cost. The insured reserve set-up is represented below (Figure 20).

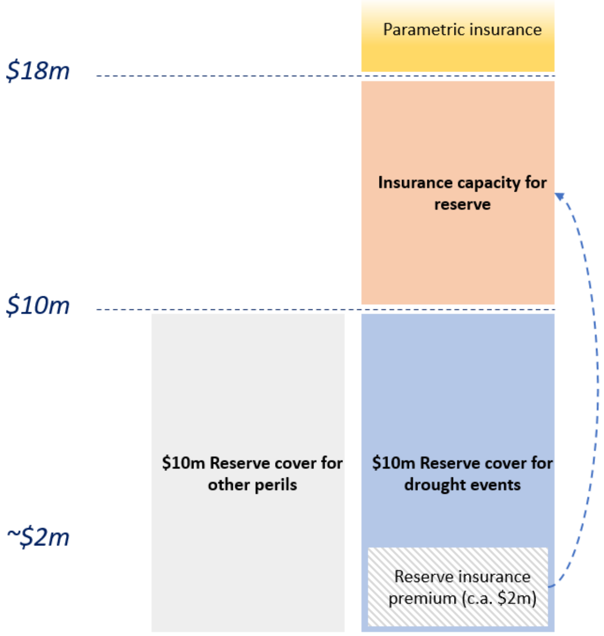


Figure 20: Illustrative set up of an insured Reserve fund
Source: AXA Climate. For illustrative purposes.

a. Reserve fund – Parametric Design 1 (SPEI)

Under the hypothesis that SPEI follows a standard normal distribution (on average amongst all *crops x territories*), a five year return period event corresponds to an attachment point at -0.84. In order to avoid protection gaps or a double compensation for the same risk, the exit point of the reserve is the attachment point of the parametric insurance scheme (i.e. a 20 year return period, for a SPEI value of -1.65).

We can summarise the payout structure in the graph below (Figure 21):

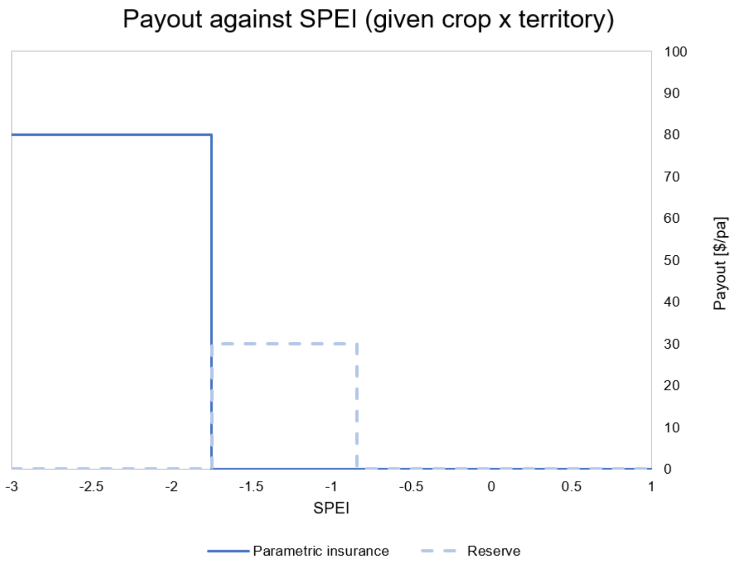


Figure 21: Payout structure parametric insurance and Reserve, SPEI
Source: AXA Climate

This figure shows how the combination of reserve and parametric insurance is creating a multilayer cover. The reserve effectively covers high frequency / low severity events while parametric insurance protects against low frequency / high severity events.

We calculated some metrics of the reserve for different setups, varying the following variables:

- **Number of payouts**: once farmers join the scheme, they cannot be excluded from the reserve cover. This however creates a geometrical exposure, which becomes critical during last years. To mitigate this effect, an hypothesis has been established with the Client that farmers can only get two payouts during the whole five years. It may however be interesting to study the impact of changing this number to one.
- **Attachment point**[6]: the reserve is expected to trigger for index events that correspond to a five year return period. This is however a high frequency. It might be necessary to decrease to seven year return period events.
- **Payout**: the limit/farmer can also be a variable. Although the target value is $30/farmer, it can be interesting to estimate the impact of decreasing this value.
- **Type of reserve**: the standalone reserve has a capacity of $10 million, whereas the insured reserve has a total capacity of $16 million ($8 million of reserve and $8 million of insurance, which has a targeted premium of $2 million).

The insured reserve requires to price an 8 XL 8 insurance on the 5 year cumulated loss. As a reminder, the total cession can be calculated as:

$$Ceded = \max(0; \min(Aggregate\ Loss - 8{,}000{,}000; 8{,}000{,}000))$$

We use the 10,000 simulations done for the index in order to estimate, for each, the ceded amount (i.e. the reserve payout to farmers). The average of the ceded amount gives the expected loss, which is then multiplied by two to give the premium (the same hypothesis was made for parametric design pricing).

The following table (Table 14) gathers all results.

---

[6] The exhaustion point does not vary however, as it is fixed by the attachment point of the parametric insurance. The exhaustion point thus corresponds to index events with a 20 year return period.

		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10	Option 11	Option 12	Option 13	Option 14	Option 15	Option 16	Option 17	Option 18
Max nb of payout/pa		2	2	1	1	2	2	2	1	1	1	2	2	1	1	2	2	1	1
Index trigger		1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)
Index exit		1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)
Payout [USD/pa]		30	20	30	20	30	20	15	30	20	15	30	20	30	20	30	20	30	20
Reserve capacity [USD]		8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000
Insurance limit [USD]		8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	-	-	-	-	-	-	-	-
Total capacity [USD]		16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000
Whole 5 years cumulated loss [USD]	Quantile 1%	2 689 259	1 792 839	2 595 174	1 730 116	739 628	493 085	369 814	734 751	489 834	367 376	2 689 259	1 792 839	2 595 174	1 730 116	739 628	493 085	734 751	489 834
	Quantile 25%	12 440 394	8 293 596	11 356 718	7 571 145	6 689 135	4 459 423	3 344 567	6 344 501	4 229 667	3 172 250	12 440 394	8 293 596	11 356 718	7 571 145	6 689 135	4 459 423	6 344 501	4 229 667
	Median	19 765 151	13 176 767	17 774 125	11 849 417	11 902 780	7 935 187	5 951 390	11 108 933	7 405 956	5 554 467	19 765 151	13 176 767	17 774 125	11 849 417	11 902 780	7 935 187	11 108 933	7 405 956
	Quantile 75%	28 629 536	19 086 357	24 963 221	16 642 147	18 815 116	12 543 410	9 407 558	17 375 437	11 583 625	8 687 719	28 629 536	19 086 357	24 963 221	16 642 147	18 815 116	12 543 410	17 375 437	11 583 625
	Quantile 99%	51 165 697	34 110 465	38 442 468	25 628 312	38 213 984	25 475 989	19 106 992	31 347 208	20 898 138	15 673 604	51 165 697	34 110 465	38 442 468	25 628 312	38 213 984	25 475 989	31 347 208	20 898 138
Whole 5 years uncovered loss [USD]	Quantile 1%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Quantile 25%	-	-	-	-	-	-	-	-	-	-	2 440 394	-	1 356 718	-	-	-	-	-
	Median	3 765 151	-	1 774 125	-	-	-	-	-	-	-	9 765 151	3 176 767	7 774 125	1 849 417	1 902 780	-	1 108 933	-
	Quantile 75%	12 629 536	3 086 357	8 963 221	642 147	2 815 116	-	-	1 375 437	-	-	18 629 536	9 086 357	14 963 221	6 642 147	8 815 116	2 543 410	7 375 437	1 583 625
	Quantile 99%	35 165 697	18 110 465	22 442 468	9 628 312	22 213 984	9 475 989	3 106 992	15 347 208	4 898 138	-	41 165 697	24 110 465	28 442 468	15 628 312	28 213 984	15 475 989	21 347 208	10 898 138
8 XL 8 insurance	EL [USD]	6 109 778	4 499 506	5 789 398	3 966 397	4 007 670	2 288 912	1 199 924	3 725 083	1 941 309	854 267	-	-	-	-	-	-	-	-
	Premium [USD]	12 219 557	8 999 013	11 578 796	7 932 795	8 015 341	4 577 824	2 399 847	7 450 167	3 882 619	1 708 534	None	None	None	None	None	None	None	None

Table 14: 8 XL 8 insurance premium and aggregate loss distribution for different insured reserve setups, SPEI
Source: AXA Climate

This charts is divided in two parts: options one to ten focus on insured reserve, while options eleven to eighteen give results for the standalone reserve. The numbers explicitely show that reserve drawdown is volatile, because of the gap between the median drawdown and its 99th percentile. Very often there is an uncovered loss, which happens when the reserve capacity is exhausted ($10 million for the standalone reserve and $16 million for the insured reserve).

Few setups comply with the $2 million insurance premium target for the insured reserve. Furthermore, as the goal is to use the reserve, it should be avoided to have a small average aggregate loss over the five years. The seventh test gives decent results and thus has been chosen to be the Insured Reserve for SPEI. The median aggregate loss over five years is a bit less than $6 million, which is still rather low. The 8 XL 8 insurance premium is close to $2 million as targeted ($2,4m), and the uncovered loss becomes positive only around the 99th percentiles. This means there is roughly one in a hundred chances under this set up that the insured reserve is unable to cover a loss.

Unfortunately, in order to obtain these results, the cover has to be degraded to offer payouts on a less frequent basis. To do so, the attachement point was decreased from -0.84 (1 in 5) to -1.07 (1 in 7), and each farmer gets a maximum of two $15 payouts over the five years.

The standalone reserve as well needs to be adapted. Indeed, the initial setup (two $30 payouts maximum per farmer) appeared to have an average drawdown of $20 million, twice as much as the reserve limit. The would has left an average uncovered loss of nearly $10 million, which seemed too high. To remedy this issue, we suggest to consider $20 payouts instead of $30 payouts, while leaving the rest of the settings unchanged (option twelve). The average drawdown of the reserve is much closer to the $10 million capacity.

b. Reserve – Parametric Design 2 (SMI)

The same analysis needs to be done to select the standalone and insured reserve for SMI based covers. The payout structure, with both parametric insurance and the reserve, is illustrated below (Figure 22).

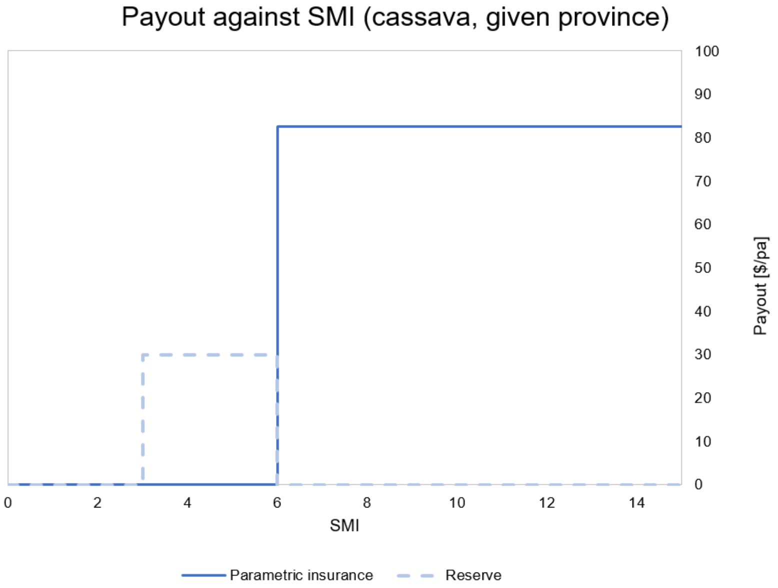
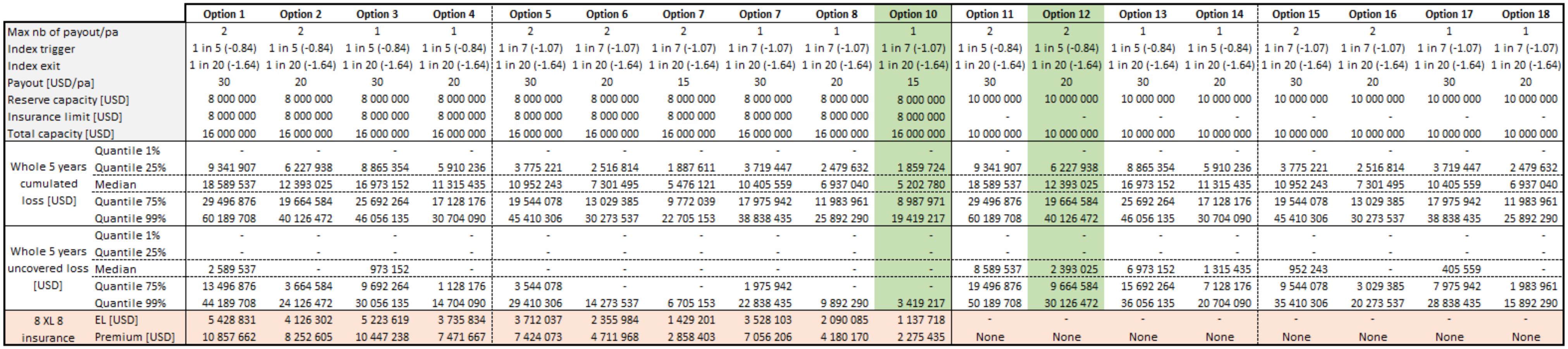


Figure 22: Payout structure parametric insurance and Reserve, SMI (illustrative thresholds)
<u>Source</u>: AXA Climate

This figure once again demonstrates the complementarity that is built between reserve and parametric insurance (even though the attachement and exhaustion points are only illustrative). We compute the same metrics as the one showed in Table 14, for the insured and standalone reserve with SMI (Table 15).



		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 7	Option 8	Option 10	Option 11	Option 12	Option 13	Option 14	Option 15	Option 16	Option 17	Option 18
Max nb of payout/pa		2	2	1	1	2	2	2	1	1	1	2	2	1	1	2	2	1	1
Index trigger		1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 5 (-0.84)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)	1 in 7 (-1.07)
Index exit		1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)	1 in 20 (-1.64)
Payout [USD/pa]		30	20	30	20	30	20	15	30	20	15	30	20	30	20	30	20	30	20
Reserve capacity [USD]		8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000
Insurance limit [USD]		8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	8 000 000	-	-	-	-	-	-	-	-
Total capacity [USD]		16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	16 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000	10 000 000
Whole 5 years cumulated loss [USD]	Quantile 1%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Quantile 25%	9 341 907	6 227 938	8 865 354	5 910 236	3 775 221	2 516 814	1 887 611	3 719 447	2 479 632	1 859 724	9 341 907	6 227 938	8 865 354	5 910 236	3 775 221	2 516 814	3 719 447	2 479 632
	Median	18 589 537	12 393 025	16 973 152	11 315 435	10 952 243	7 301 495	5 476 121	10 405 559	6 937 040	5 202 780	18 589 537	12 393 025	16 973 152	11 315 435	10 952 243	7 301 495	10 405 559	6 937 040
	Quantile 75%	29 496 876	19 664 584	25 692 264	17 128 176	19 544 078	13 029 385	9 772 039	17 975 942	11 983 961	8 987 971	29 496 876	19 664 584	25 692 264	17 128 176	19 544 078	13 029 385	17 975 942	11 983 961
	Quantile 99%	60 189 708	40 126 472	46 056 135	30 704 090	45 410 306	30 273 537	22 705 153	38 838 435	25 892 290	19 419 217	60 189 708	40 126 472	46 056 135	30 704 090	45 410 306	30 273 537	38 838 435	25 892 290
Whole 5 years uncovered loss [USD]	Quantile 1%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Quantile 25%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Median	2 589 537	-	973 152	-	-	-	-	-	-	-	8 589 537	2 393 025	6 973 152	1 315 435	952 243	-	405 559	-
	Quantile 75%	13 496 876	3 664 584	9 692 264	1 128 176	3 544 078	-	-	1 975 942	-	-	19 496 876	9 664 584	15 692 264	7 128 176	9 544 078	3 029 385	7 975 942	1 983 961
	Quantile 99%	44 189 708	24 126 472	30 056 135	14 704 090	29 410 306	14 273 537	6 705 153	22 838 435	9 892 290	3 419 217	50 189 708	30 126 472	36 056 135	20 704 090	35 410 306	20 273 537	28 838 435	15 892 290
8 XL 8 insurance	EL [USD]	5 428 831	4 126 302	5 223 619	3 735 834	3 712 037	2 355 984	1 429 201	3 528 103	2 090 085	1 137 718	-	-	-	-	-	-	-	-
	Premium [USD]	10 857 662	8 252 605	10 447 238	7 471 667	7 424 073	4 711 968	2 858 403	7 056 206	4 180 170	2 275 435	None	None	None	None	None	None	None	None

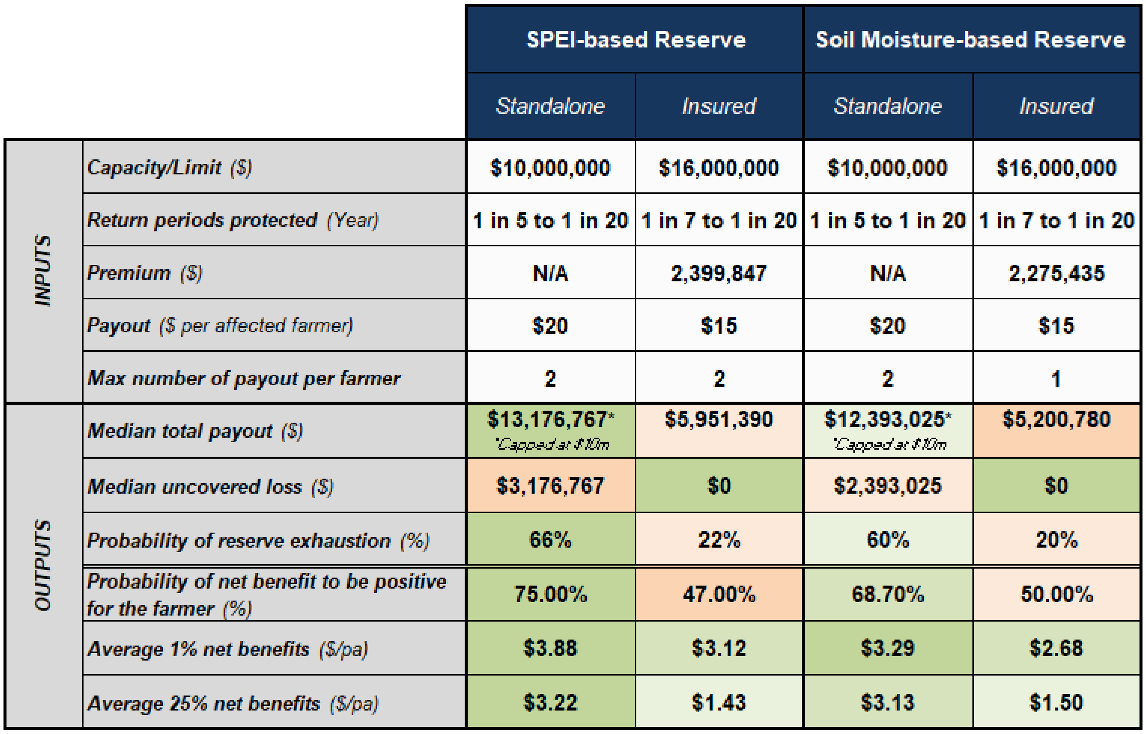
Table 15: 8 XL 8 insurance premium and aggregate loss distribution for different insured reserve setups, SMI
Source: AXA Climate

As in the previous subsection, the chart is divided between insured reserve setups (options one to ten) and standalone reserves (options eleven to eighteen). The reserve seems even more volatile than in SPEI case, which is due to the difference of trigger granularity. The SPEI reserve triggers at *crop x territory* granularity, whereas the SMI reserve triggers at *crop x province* granularity. This reduces diversification, and a lack of diversification mechanically increases volatility. Furthermore, as the payout is made at the province level, its amount is higher as it covers all the territories within the province.

We choose options that are consistent with the choices made in the SPEI reserve subsection before. We propose to select option ten for the insured reserve, as it complies with the $2 million premium target. The SMI insured reserve only offers one payout of $15/farmer instead of a maximum of two payouts for the SPEI insured reserve. The standalone reserve can be option twelve, with a decrease of payout per farmer ($20 instead of $30) compared to what was initially planned. This is also the option that was selected for the standalone SPEI reserve.

c. *Recap of results*

The following table (Table 16) summarizes the main characteristics of selected options for insured and standalone reserves, both for SPEI and SMI.



		SPEI-based Reserve		Soil Moisture-based Reserve	
		Standalone	*Insured*	*Standalone*	*Insured*
INPUTS	***Capacity/Limit*** *($)*	**$10,000,000**	**$16,000,000**	**$10,000,000**	**$16,000,000**
	Return periods protected *(Year)*	**1 in 5 to 1 in 20**	**1 in 7 to 1 in 20**	**1 in 5 to 1 in 20**	**1 in 7 to 1 in 20**
	Premium *($)*	**N/A**	**2,399,847**	**N/A**	**2,275,435**
	Payout *($ per affected farmer)*	**$20**	**$15**	**$20**	**$15**
	Max number of payout per farmer	**2**	**2**	**2**	**1**
OUTPUTS	***Median total payout*** *($)*	**$13,176,767*** **Capped at $10m*	**$5,951,390**	**$12,393,025*** **Capped at $10m*	**$5,200,780**
	Median uncovered loss *($)*	**$3,176,767**	**$0**	**$2,393,025**	**$0**
	Probability of reserve exhaustion *(%)*	**66%**	**22%**	**60%**	**20%**
	Probability of net benefit to be positive for the farmer *(%)*	**75.00%**	**47.00%**	**68.70%**	**50.00%**
	Average 1% net benefits *($/pa)*	**$3.88**	**$3.12**	**$3.29**	**$2.68**
	Average 25% net benefits *($/pa)*	**$3.22**	**$1.43**	**$3.13**	**$1.50**

Legend: Efficiency in reducing farmers' risk : **High** **Low**

Table 16: Recap of main characteristics, insured and standalone reserves, based on SPEI and SMI
Source: AXA Climate

***When insured*, the reserve fund needs weaker parameters** – lower payout/farmer, lower number of payouts/ farmer, attachment point for rarer events – in order to have a reasonable insurance premium. The net benefits are steady from one year to the other, but they are smaller than what can be expected from a standalone reserve due smaller payouts and to the (fictional) hypothesis that the premium is paid by farmers themselves.

Both options are rather similar, despite the inherent differences of the structures between parametric insurance Design 1 and 2. The main difference is that the insured reserve based on SMI only offers one 15$/farmer payout at maximum, whereas the insured reserve based on SPEI offers two.

***When not insured*, the reserve fund is effective but can be exhausted early.** The average net benefit of farmers is positive for nearly 70% of the simulations. The weakness of this set-up is that the reserve is exhausted in more than 60% of the simulations, leaving farmers unprotected for the final years. We however recommend not to insure the reserve anyway as the cost of the cover is too high compared to its benefits.

4 – COST-BENEFIT ANALYSIS

This final section focuses on cost-benefit analysis. The first subsection describes the overall method that is used to compute revenues and costs, in order to derive the benefits. The second subsection moves on to the Base Case, first by giving its definition, then by analysing the results. Finally, the last subsection dives into sensitivities. We first define these different scenarios and explain their selection, before moving on to the sensitivities results and discussion.

The CBA exercise is useful in that it allows to estimate the cost-effectiveness of the different options tested. However, a CBA remains a model, and therefore must make simplifying assumptions that differ from reality and which are limits to the results. **Several limitations of the CBA can be mentioned**:

- **The assumption that the cost of the reserve fund (opportunity cost) and the cost of the insurance (premium cost) is borne by the farmers**. This assumption makes it possible to calculate the net benefit of the coverages by subtracting their costs from their benefits, without which it would be impossible to have an idea of their cost efficiency. However, this assumption is purely fictitious: the reserve fund is made up of funds lent by the Client, and the insurance premium is paid byan international risk financing facility. The benefit of the solution for the farmers, in practice, does not take into account the cost of the solution: it corresponds to the "benefits" column of the CBA.

- **The correlation between index and yield tackled as a sensitivity**. For each cover design, the CBA Base Case adopts the hypothesis of a 100% correlation between the weather data (ERA5) and the farmers' yields, which implies that the latter can be perfectly predicted by the former. This assumption is necessary to calculate the theoretical benefits of the solution, because there is no yield data available in DRC to estimate properly this correlation. This makes correlation a part of sensitivity analysis, whereas it should be the cornerstone upon which the Parametric Design is chosen. In practice, the correlation is not expected to be higher than 60%. The relaxation of the correlation hypothesis in the sensitivity analyses reveals a high basis risk, i.e. a risk of not compensating farmers when the situation requires it (negative basis risk) or of compensating them when their harvest has been good (positive basis risk).

- **The maize and cassava prices used in the CBA date back from an estimate made in 2012**. These prices are crucial in that they allow the calculation of farmers' incomes resulting from their harvest, which is the starting point of the CBA. Sensitivity tests show that net benefits (and thus cover efficiency) are highly dependent on the adequation between limit per crop and actual crop valuation. It would be relevant in the final construction of the product to obtain a more recent estimate of crop prices (time series format) in order to adjust the compensation amount and/or the per-crop limit if necessary.

- **The cost estimate is simplistic.** The costs of each coverage alternative have been simplified: the cost of pre-allocating funds in a reserve have been included in an overall opportunity cost of 25% of the funds set aside, while insurance costs are included in the premium cost. In practice, there will be other implementation expenses (*e.g.* costs of implementing the reserve fund, costs of activating the soft trigger, costs of distributing the payout, costs of structuring the insurance solution by a broker, *etc.*). The amount of these costs will only be known once the solution is deployed, which is why it was decided not to take them into account at the CBA stage.

- **In general, given the travel restriction imposed by COVID-19, no in-person discussions have taken place between AXA Climate and the DRC government for this feasibility study**. Some assumptions could therefore be adjusted based on the feedback and priorities of the government.

1. CBA method

a. Revenue benefits

We estimate benefits by comparing the revenues of farmers with and without protection. The net benefit is the difference between protected and unprotected revenues, considering costs as negative cash flows in protected revenues. Benefits are the difference between protected and unprotected revenues, with no consideration of cost. The global relationship between all these values is *Net Benefits = Benefits – Costs*.

For a given year *y* in a simulated trajectory *i*, we compute farmers' revenues as follows: simulated crop yield *times* simulated crop price (based on prefeasibility study's approach) *times* protected surface area. In mathematical terms:

$$Revenue_{y,i}^{Unprotected} = \sum_{crop} area_{crop,y,i} \text{ x } yield_{crop,y,i} \text{ x } price_{crop}$$

The protected revenue is then calculated as the unprotected revenue, with the payouts (if any) minus the costs:

$$Revenue_{y,i}^{Protected} = Revenue_{y,i}^{Unprotected} + payouts_{y,i} - costs_{y,i}$$

We can use several metrics to get a grasp on the protection offered by the protection scheme, for instance by taking the average net benefits value across all 10,000 yield runs. A more relevant metrics though, in "risk terms", is the net benefits when yield is very low, which is when the insurance or the reserve fund cover are needed. We thus represent the benefits across the distribution of revenues by showing the benefits in good (99% and 75% percentile), median (50%) and bad years (25% and 1%) in terms of aggregated revenues at country level.

Specifically, **we calculate the benefits at a given percentile as the dollar difference between unprotected and protected revenues**. Intuitively, we compare two worlds – one with protection and without it.

b. Costs

Parametric Designs costs for the Risk Transfer product

In the cost-benefit analysis, the annual costs are expressed in USD per participant. This is a fictional hypothesis used to calculate net benefits, as the cost of the premium will not be supported by farmers under the program. To calculate the annual cost per participant, we use the annual premium and divide it by the maximum number of insured for each year. Insurance costs are not variable since the premium is fixed before the beginning of the cover.

Reserve costs

The main costs of the reserve are the costs of not using these funds for productive investments. These are the "opportunity costs" of setting aside $10 million for climate risks. The opportunity costs are defined as the rate of return on the best alternative investments. We assume in the context of this study that the alternative investments would be in the agricultural sector and in line with this history of the Client investments.

Our main source to evaluate the rate of return of these investments is the report published by the World Bank's Independent Evaluation Groupe (*cf.* WORLD BANK [2010]). The report centralizes information on the rate of return of projects supported by the World Bank from 1972 to 2008. It breaks down the analysis by sector including for the agricultural one. The following chart presents the results of this data collection for the agricultural sector.

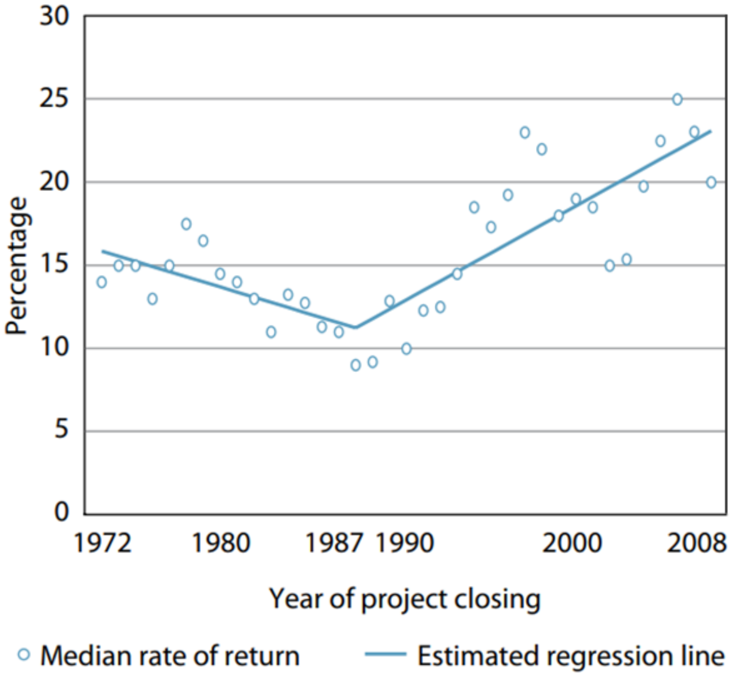


Figure 23: Rate of return observed on World Bank agriculture and rural development projects
Source:Derived from WORLD BANK [2010], p.37

The chart indicates that the most recent rate of return observed range between 20-25%. It also shows an upward trend in the rates of return from 1990 to 2008. The report investigates potential reasons for this upward trend including a "*rise in upward bias in returns, improvement in overall economic conditions as measured by growth, and a rise in the degree of market orientation of the economic regime"* with mixed results depending on the countries analyzed (which do not include the DRC).

The report did not consider the potential effect of global equity risk premium levels, which were particularly high in the years leading up to the dot-com bubble (2000) and Global Financial Crisis (2007/8). This equity risk premium is currently at a similar or higher level than in those years. We therefore suggest using the upper bound of the range – 25% – as the opportunity costs of the reserve funds.

In the cost-benefit analysis, the annual costs are expressed in $ terms per participant (*i.e.* 25% applied to the funds frozen and divided by the number of farmers covered). Once funds have been withdrawn in the form of payout, there is no opportunity cost to the funds as they are not available for alternative usage. To calculate the costs per participant, we use the total number of participants over the five years of the programme since the participants onboarded in year 5 benefit from the fact that funds were frozen in the years before they come on board.

Operationnal costs

The operational costs of the reserve funds consist in the operational costs of setting the funds in a bank account, monitoring the events affecting the agricultural output in the territories concerned and trigger and allocating the transfers when needed.

As the reserve fund is still at an exploratory phase, it is not clear what those different implementations costs would be. A reasonable proxy for it could be the operational costs of the parametric insurance product which are somewhat below 3% in our modelling. Given the scale of the opportunity costs, we however consider that this operational cost would not be significant and therefore propose to leave it as a discussion point in the implementation analysis of this project.

2. Base Case

a. Definition

The "Base Case" is an hypothetical scenario representing the simplest case possible. We will proceed from the "Base Case" to more complexity and realism by relaxing assumptions. The purpose of this approach is to enable the reader to clearly understand the impact of each assumption separately.

Our hypotheses are separated in three main themes:

- *Climate change* hypotheses determine how we suppose the yield and index to evolve in the next five years because of climate change;
- *Performance* hypotheses relate to the correlation between index and yield (index performance) as well as the annual yield improvement due to the package for improved production;
- *Economics* hypotheses detail the different hypotheses made on prices and discount rate.

Climate change

As the "Base Case" scenario relies on the simplest hypothesis, we assume no future trend for yield and index due to climate change. This means that the index (and yield) average and volatility will stay the same over the next five modelled years. Sensitivity will be introduced by adding one "Optimistic" climate change scenario as well as one "Pessimistic".

Performance

CSA Package performance: for the "Base Case", we assumed the production improvement package has no impact on yield average. This is another sensitivity, based on Client hypothesis regarding yield increase for cassava and maize.

Index performance: another important hypothesis is the correlation between index and yield. Since there is no reliable yield historical data in DRC, this correlation will necessarily be the result of an assumption. In a base case context, we make the hypothesis that correlation between index and yield for a given crop *x* territory (or crop *x* province in the SMI case) is 100%. This is an ideal case, and the sensitivity will bring a more realistic view on this correlation with a performance and a non-performance scenario.

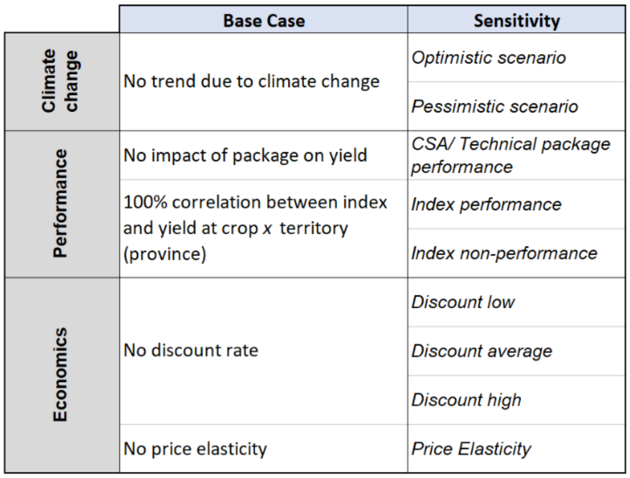
Economics

Elasticity: the Base Case assumes no price reaction ("elasticity") to yield shock. This means that a shock in yield is not compensated by an opposite variation in prices. This hypothesis will be relaxed in sensitivity analysis by adding a price elasticity scenario.

Discount rate: the Base Case uses no discount rate. The sensitivity analysis will add three scenarii, one "base estimate" and variations around this average (high and low scenario).

Recap

To summarize, the following Table (Table 17) provides an overview of Base Case hypothesis as well as the future sensitivity scenario that will be detailed in the last subsection:



	Base Case	Sensitivity
Climate change	No trend due to climate change	*Optimistic scenario*
		Pessimistic scenario
Performance	No impact of package on yield	*CSA/ Technical package performance*
	100% correlation between index and yield at crop *x* territory (province)	*Index performance*
		Index non-performance
Economics	No discount rate	*Discount low*
		Discount average
		Discount high
	No price elasticity	*Price Elasticity*

Table 17: Recap of Base Case hypothesis, and sensitivities
<u>Source</u>: AXA Climate

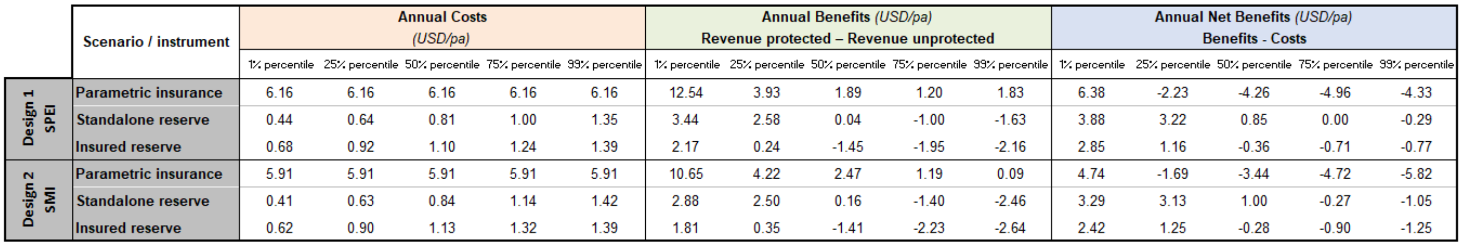
b. Base Case Results

This subsection gives the CBA results for the Base Case scenario. The goal is to compare Parametric Designs 1 and 2, and then for each Parametric Design, model the Standalone and Insured Reserve – making a total of six products.

The goal of this subsection is to determine which of the reserves (Insured or Standalone) is to be selected to build the Hybrid structure. It starts with the general results and a first macro analysis. Then it explores the difference between parametric insurance Design 1 and 2, before moving on to the comparison between Insured Reserve and Standalone Reserve. The latter aims at deciding what kind of reserve we want to keep for Hybrid structures 1 and 2 (parametric insurance + Reserve). Once we have decided what are the final instruments we select, we can move on to comparing Hybrid Structures themselves (for SPEI and for SMI).

Main results

The following table (Table 18) gives the cost-benefit analysis results of the main instruments for the Base Case scenario.



	Scenario / instrument	Annual Costs *(USD/pa)*					Annual Benefits *(USD/pa)* Revenue protected – Revenue unprotected					Annual Net Benefits *(USD/pa)* Benefits - Costs				
		1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile
Design 1 SPEI	**Parametric insurance**	6.16	6.16	6.16	6.16	6.16	12.54	3.93	1.89	1.20	1.83	6.38	-2.23	-4.26	-4.96	-4.33
	Standalone reserve	0.44	0.64	0.81	1.00	1.35	3.44	2.58	0.04	-1.00	-1.63	3.88	3.22	0.85	0.00	-0.29
	Insured reserve	0.68	0.92	1.10	1.24	1.39	2.17	0.24	-1.45	-1.95	-2.16	2.85	1.16	-0.36	-0.71	-0.77
Design 2 SMI	**Parametric insurance**	5.91	5.91	5.91	5.91	5.91	10.65	4.22	2.47	1.19	0.09	4.74	-1.69	-3.44	-4.72	-5.82
	Standalone reserve	0.41	0.63	0.84	1.14	1.42	2.88	2.50	0.16	-1.40	-2.46	3.29	3.13	1.00	-0.27	-1.05
	Insured reserve	0.62	0.90	1.13	1.32	1.39	1.81	0.35	-1.41	-2.23	-2.64	2.42	1.25	-0.28	-0.90	-1.25

Table 18: Summary of cost-benefit analysis results
Source: AXA Climate
Note 1: percentile levels reflect the underlying distribution of revenues. The 1% percentile corresponds to a succession of bad harvest years while 99% correspond to very good years.

The first noticeable result is that cost is fixed for insurance products, whereas it varies for reserves. This is due to the fact that insurance costs are only determined by the annual premium, which does not vary once calculated, whereas reserve costs are directly linked to its drawdown. The more money is withdrawn from the reserve, the more the opportunity cost of the reserve is reduced as less money is set aside "unproductively". This explains why the cost of the reserve is lower for very bad yield years ($0.44 annually per participant averaged over 5 years at the 1% percentile for the SPEI Standalone reserve) than for good years ($1.35 at the 99% percentile).

A second preliminary observation is that parametric insurance (both SPEI and SMI) offers positive net benefits for the very firsts percentiles, but not after. This is expected, to the extent that this insurance protects against low frequency events (around the 1% percentile of revenues). The "good" years, *i.e.* higher percentiles, won't get any payout while paying the premium, which explains why net benefits become negative. The reserves (insured and standalone, based on SPEI and SMI), however, have positive net benefits until the 25% percentile and higher. This is due to the fact that reserves cover events that are more frequent, and have potentially less costs than insurance.

The subsections below dive into detailed product comparisons and analysis.

Comparison 1*: Parametric insurance Design 1 against Design 2*

These paragraphs investigate the difference of net benefits for parametric insurance Design 1 (SPEI) and 2 (SMI). Both covers protect farmers against 1 in 20 year return period events and worse, for a five year cumulated premium of nearly $20 million. These covers are comparable in terms price and risk. Figure 24 shows the average net benefits over 5 years against protected revenues for both products. The goal is to compare the cover quality brought by each design. Parametric Design 1 (SPEI) seems to bring more net benefits than Parametric Design 2 (SMI).

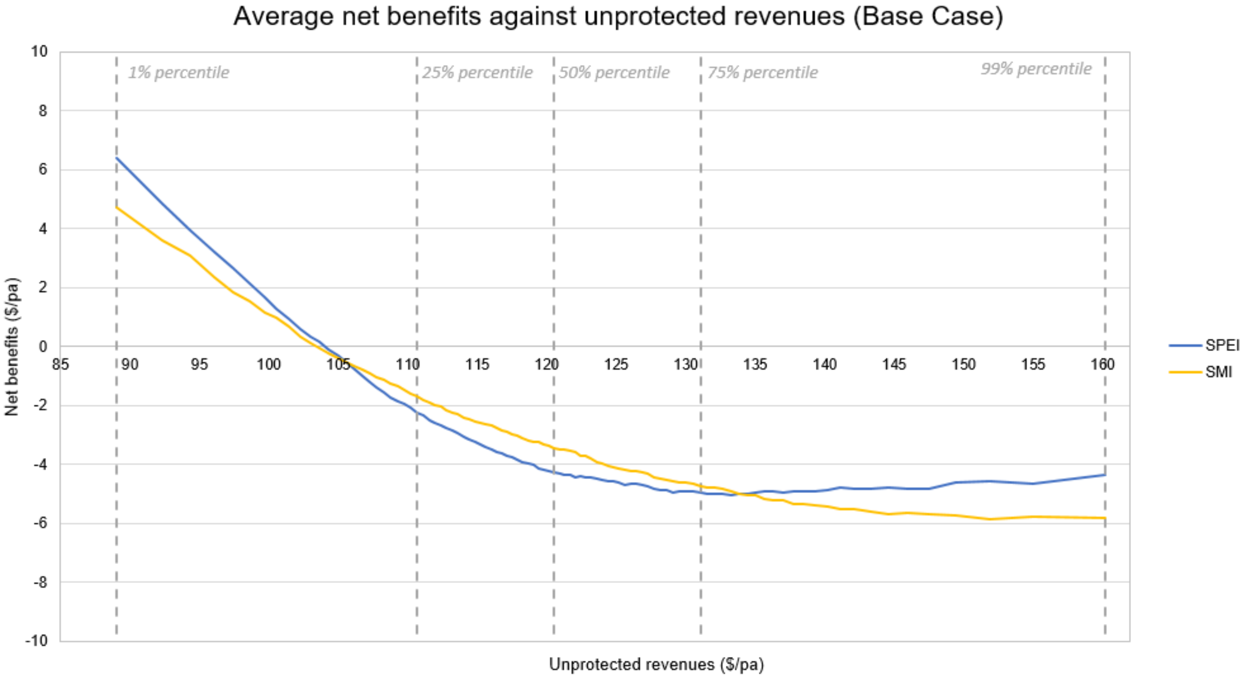


Figure 24: Net benefits against unprotected revenues, Parametric Design 1 (SPEI) and 2 (SMI)
Source*: AXA Climate*

Both covers have a **profitability threshold at approximately 10%**, which corresponds to an average unprotected revenue of $105/farmer. The SPEI net benefits are higher around the tails of the distribution (1% percentile and 99% percentile), but smaller in the middle (25% percentile to 50% percentile). However, for an average year, corresponding to a 50% percentile revenue at $120/farmer, the SMI product has a higher net benefit than the SPEI.

It is difficult to establish precisely the reasons behind these differences. Having a per province trigger for the SMI tends to increase the payout amount compared to a per territory trigger, however at the same time we differentiated the limit per crop with the SMI cover and decreased the maize indemnity. The latter point probably explains why the net benefits of SMI do not increase around the 99% percentile of revenues whereas the SPEI do. This is due to the fact that SPEI pays $80/farmer regardless of the crop, although as we discussed in section **2.1.** (Table 9) maize brings less to the average revenue than cassava. The overestimation of payout for maize, in the SPEI cover, triggers some extreme cases where the payout is actually so high compared to the average revenue that the protected revenue corresponds to the best unprotected revenues. This causes even the 1% percentile to be negative, because the insurance premium is too high compared to the average revenue for the territory (see Figure 25 below):

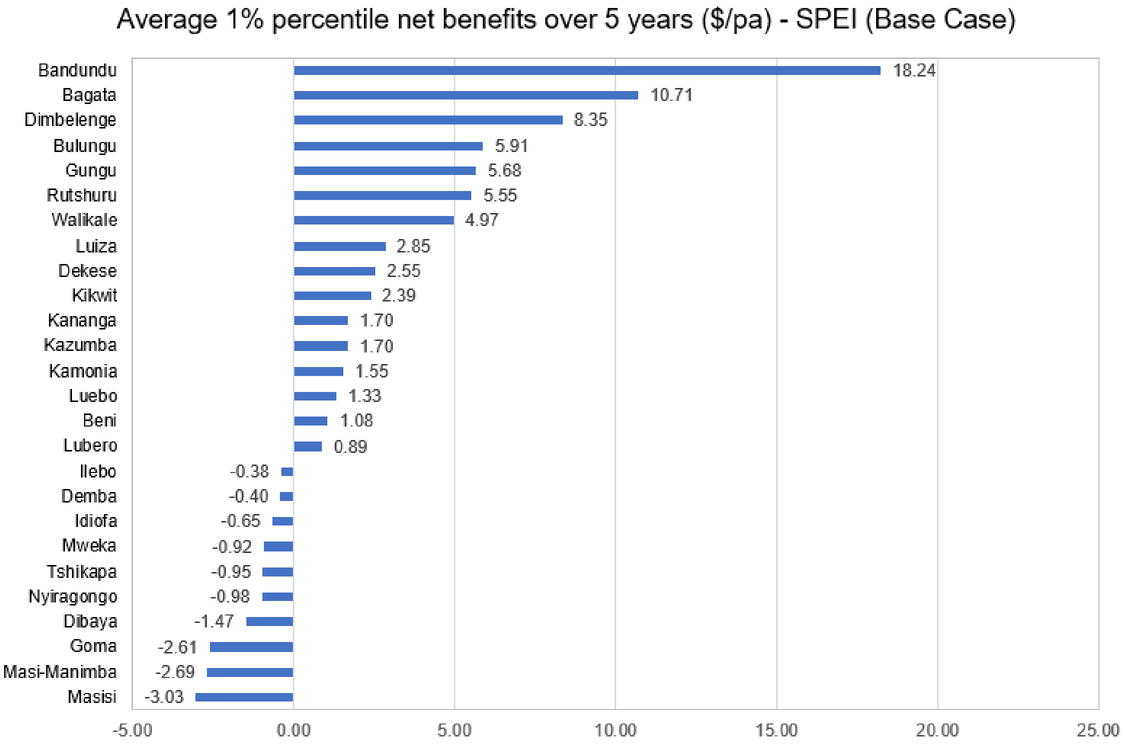


Figure 25: Net benefits at 1% percentile ($/pa) per territory, Parametric Design 1
<u>Source</u>: AXA Climate

Overall, the **SMI cover enables to bring less disparity** between territories and provinces than the SPEI cover. This is reflected in the comparison of the net benefits at 1% percentile by province in each case (Figure 26).

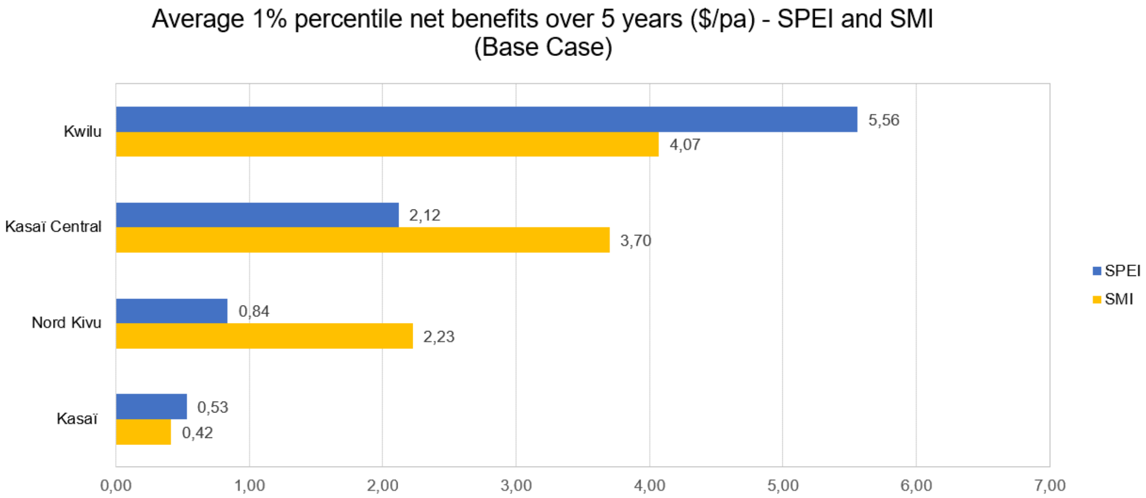
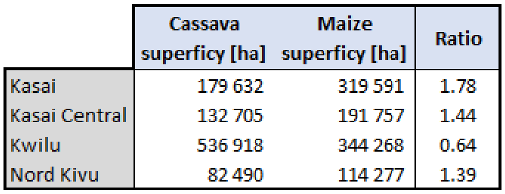


Figure 26: Net benefits at 1% percentile ($/pa) per province, Parametric Design 1 & 2
<u>Source</u>: AXA Climate

It is surprising to note that despite the efforts made to reduce disparity between provinces under the SMI cover (*i.e.* introducing a differentiated trigger threshold by *crop x province* and a limit by crop), Kasaï province has still a significantly lower net benefit at 1% percentile than other provinces. This might be due to the fact that maize payout is over-estimated compared to maize value (see Table 9), and that Kasaï has the highest maize to cassava superficy ratio (see Table 19 below and Appendix 3 for further details).



	Cassava superficy [ha]	Maize superficy [ha]	Ratio
Kasai	179 632	319 591	1.78
Kasai Central	132 705	191 757	1.44
Kwilu	536 918	344 268	0.64
Nord Kivu	82 490	114 277	1.39

Table 19: Maize to Cassava superficy ratio, by province
<u>Source</u>: Derived from Table 6

As a final recap of this comparison between Parametric Design 1 (SPEI) and 2 (SMI), it can be observed that :

- Parametric Design 1 has less basis risk than Parametric Design 2 because it triggers at territory level. This explains why it protects better, on average, the lower tail of the distribution. This causes the 1% percentile net benefits to be higher than the Parametric Design 2 one;
- Parametric Design 2 decreases disparity between provinces by having a differentiated trigger threshold by province, as well as a different limit for cassava and maize;
- Both Parametric designs have a similar profitability point at approximately 10% and a \$5-\$6/farmer net benefits at 1% percentile.

<u>Note</u>: based on these learnings, the fourth subsection of this chapter proposes a Parametric Design 3 which performs better than Parametric Designs 1 and 2 thanks to the combinaison of a payout at territory level, a limit per crop and the use of soil moisture index.

***Comparison 2**: Standalone reserve against Insured reserve*

It might be counter-intuitive for the reader to find out that the net benefits of the insured reserve are lower than the standalone reserve (both in SMI and SPEI). This is all the more so unexpected in very bad revenues years (1% percentile), where one would expect insurance to pay more than a reserve fund only. These results are however correct. They are explained by the difference in the underlying hypothesis and parameters of the two instruments. As discussed in section **3.3.** of this report, the insured reserve has smaller payouts ($15/farmer instead of $20/farmer) and an average drowndawn way smaller because of a higher attachment point (between $5 million and $6 million of drawdown for the insured reserve against $13 million for the standalone reserve). This degradation of cover for the insured reserve was necessary in order to comply with the $2 million premium target, which causes the insured reserve to pay on average less than the standalone reserve. This explains why the standalone reserve seems more profitable for farmers. Since the reserve drawdown is very volatile and that the goal is to use the capacity as much as possible, the reserve is very hard to insure with reasonable premium.

The advantage of the insured reserve compared to the standalone reserve, however, is the limitation of uncovered loss. Indeed, the standalone reserves (both SPEI and SMI) reach exhaustion with approximately a 60%-70% probability, against roughly 20% probability for insured reserve. In worst cases (worst 1% outcomes), the standalone reserve is exhausted during year 3 out of 5, leaving the two last years uncovered. This is clearly showed by the four figures below, gathered in Figure 27. Each figure shows the reserve drawdown, with different trajectories (1% percentile, 25% percentile, 50% percentile, 75% percentile and 99% percentile). The dashed grey lines show the capacities (the first one for the reserve itself, and the second for reserve and insurance).

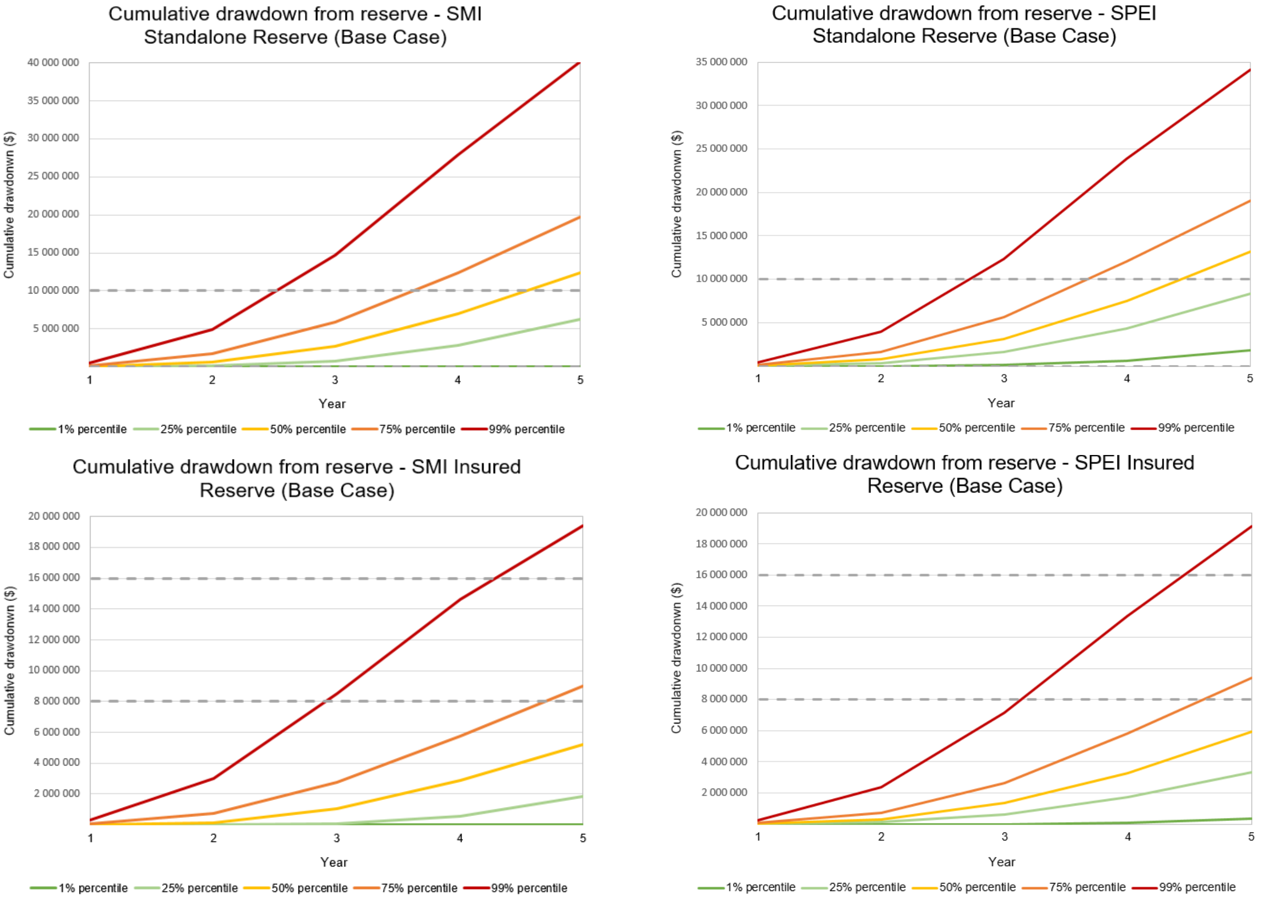


Figure 27: Reserves cumulative drawdown (SPEI & SMI, Insured and Standalone reserves)
Source: AXA Climate

These graphs show there are similarities between SMI-based reserves and SPEI-based reserves. We will thus continue our comparison of Insured Reserve against Standalone Reserve by focusing on the SMI reserve, while all remarks and analysis are applicable for the SPEI-based reserves.

The decrease of net benefits for the last years with the insured reserve appears clearly when looking at the net benefits against unprotected revenues, per year. This graph is similar to Figure 24, except there is one line per year, in order to show that there is a degradation of the cover with the standalone reserve as years go by (Figure 28).

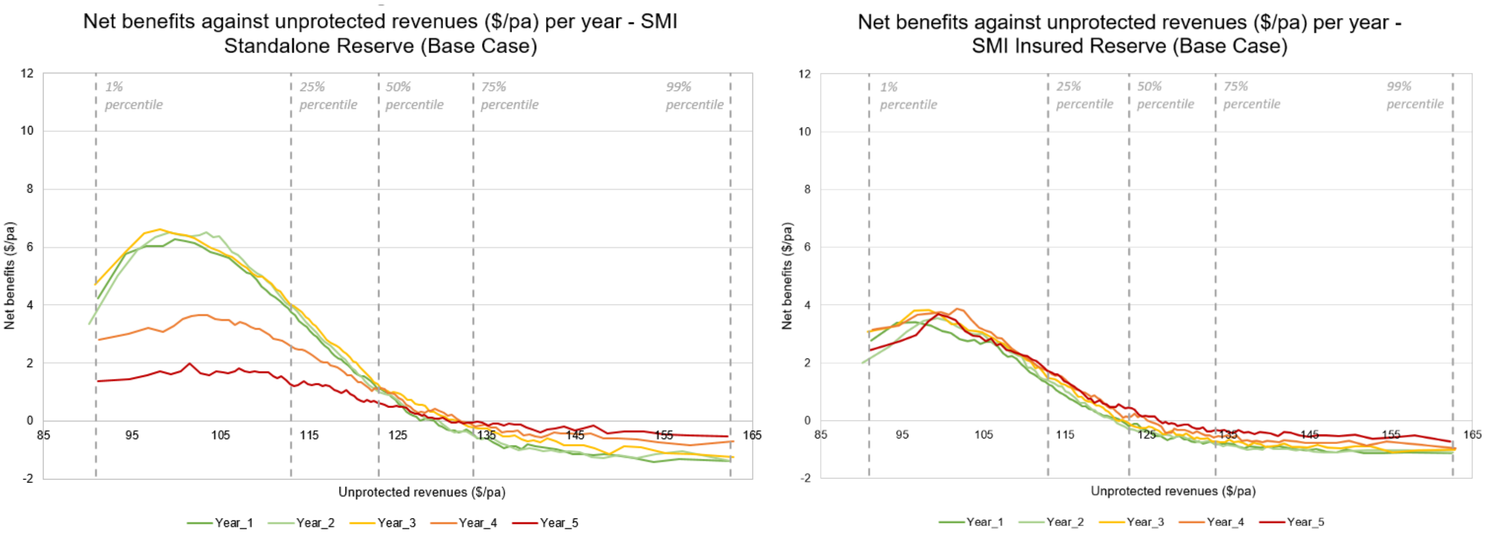


Figure 28: Net benefits against unprotected revenues, Insured and Standalone reserves (SMI)
<u>Source</u>: AXA Climate

This figure shows that the standalone reserve's net benefits around 10% percentile is divided by three between year one and year five, because of reserve exhaustion. The insured reserve provides, on the other hand, a stable net benefits that does not vary over the years. It is possible to note however that the net benefits brought by the standalone reserve for year four (which is the lowest amongst the five years) is within the same order of magnitude than the net benefits of the insured reserve for every year.

This tends to show that an insured reserve is not optimal. This is due to the fact that reserve drawdown is very volatile, and that the goal of the reserve is to be exhausted at the end of the five year coverage. For these reasons, an excess of loss cover for the reserve is very expensive, unless the reserve cover is reduced enough. As a result, **it seems more reasonable <u>not</u> to insure the reserve and to set up a standalone reserve as part of the hybrid cover** (parametric cover & Reserve).

Uncovered losses with the Standalone reserve set up remain an issue, this is why the final set up decision will depend on the risk appetite of the Client.

***Comparison 3**: Hybrid structures*

Building upon the previous results, this last section aims at comparing Hybrid structures (*i.e.* structures combining a Reserve and parametric insurance). There is one hybrid structure per index, *i.e.* Hybrid structure 1 for SPEI, and Hybrid structure 2 for SMI. The first step is to evaluate the complementarity achieved between Reserve and parametric insurance, before moving on to comparing hybrid structures.

The goal was to build complementarity between parametric insurance and the reserve. This complementarity was achieved through trigger thresholds selection, to ensure that parametric insurance protects against index event with a return period of 20 years and above, while standalone reserve protects against index events with return periods ranging from 5 to 20 years. The analysis of the average net benefits over five years for all instruments shows that insurance and reserve do cover complementary layers of revenues (Figure 29 and Figure 30).

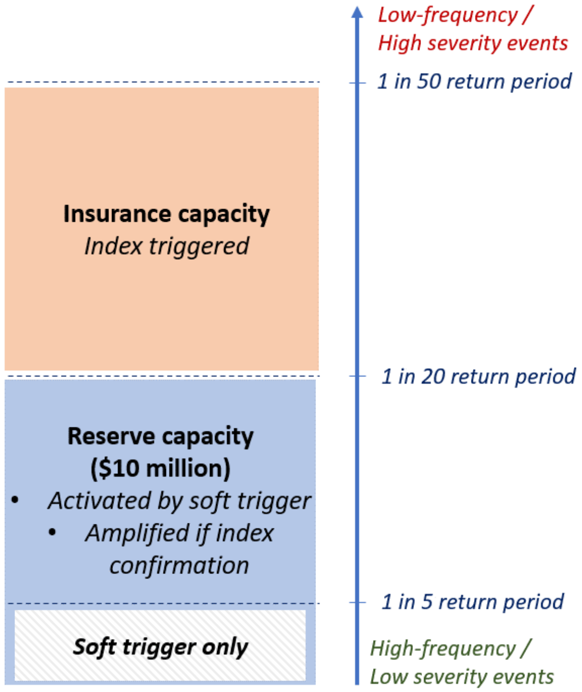


Figure 29: Illustration of the Hybrid structure
Source: AXA Climate. For illustrative purposes.

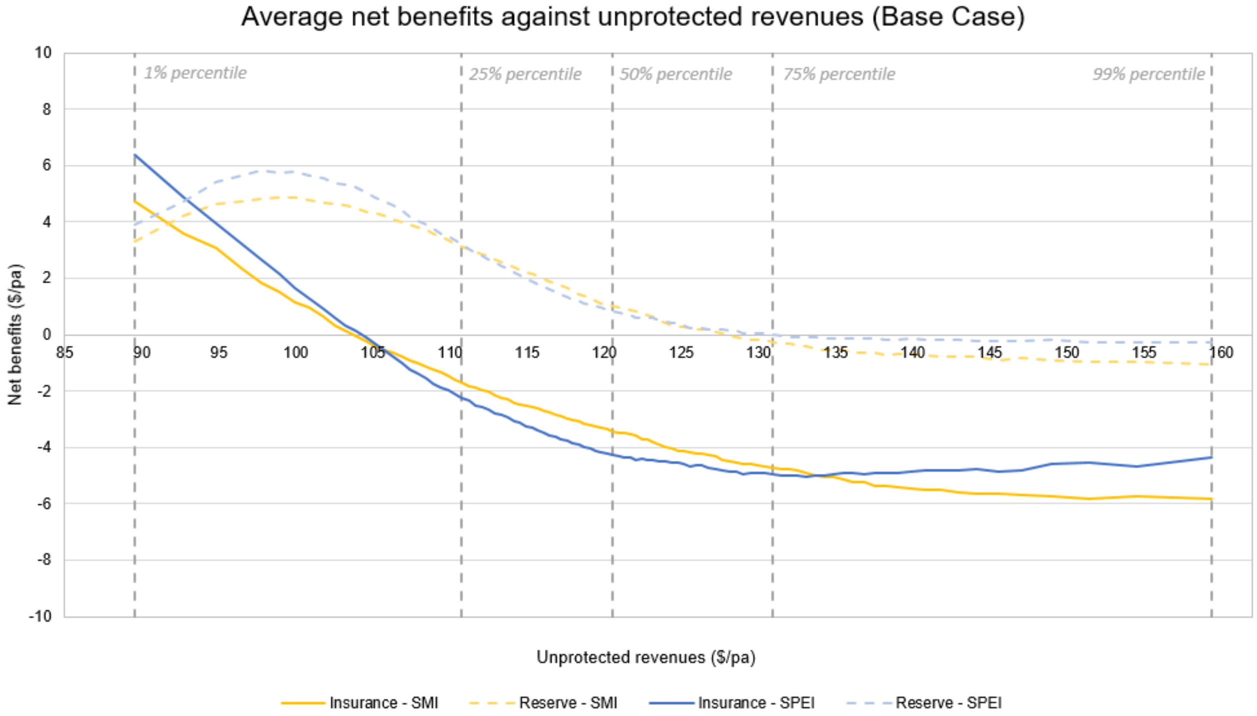


Figure 30: Net benefits average over 5 years against unprotected revenue, all instruments
Source: AXA Climate

Figure 30 shows that Parametric insurance and reserve complete each other, although there appears to be a revenue layer that is covered twice (from $90/farmer to $105/farmer). This is due to the fact the we look at the average aggregate revenue, *i.e.* all crops and territories combined, at country level. For a bad year corresponding to a 10% probability of occurrence at aggregate level (approximately $102/farmer unprotected revenue), some territories might trigger the parametric insurance, some others might trigger the reserve, while the rest have good enough index value to trigger no payout at all. This is how, at aggregate level, parametric insurance and the reserve sometimes protect the same revenue layer. This dynamic is normal and does not exist at *crop x territory* (or *crop x province* for SMI based cover) granularity.

If we consider the overall benefits of the Hybrid structures (*i.e.* combining parametric insurance and standalone reserve, for SPEI and SMI separately), we get the average benefits as displayed in Figure 31 (see below).

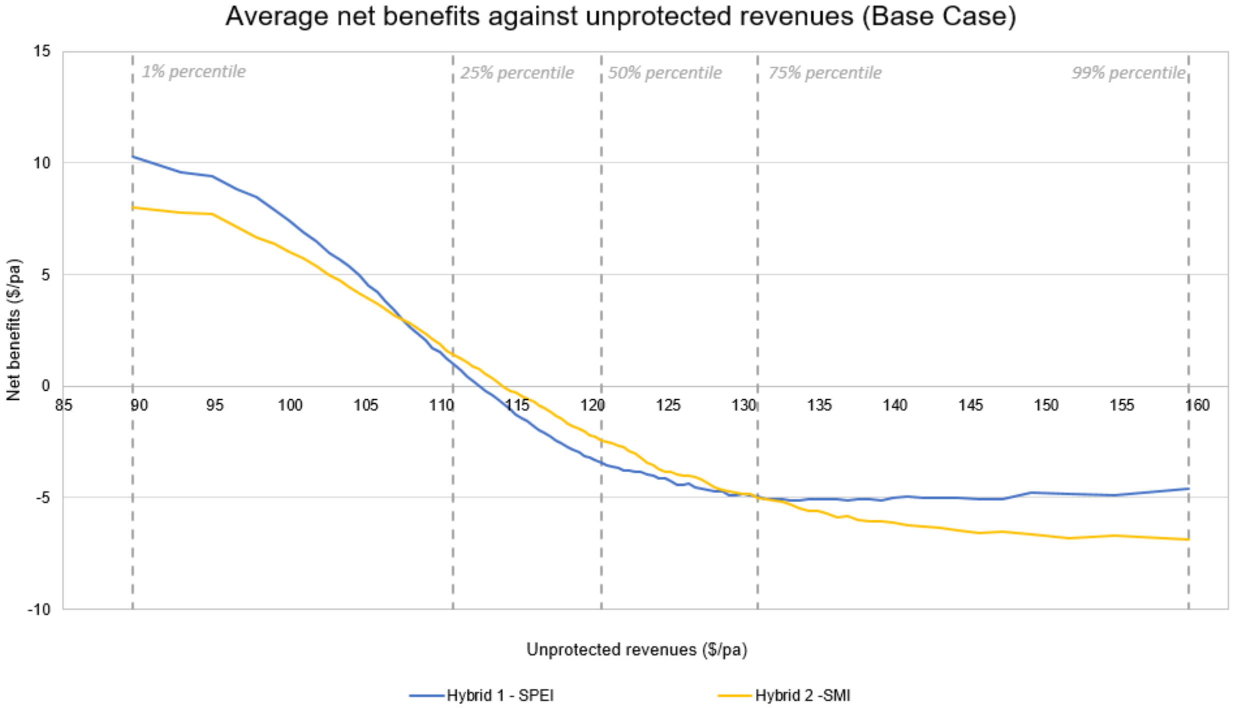
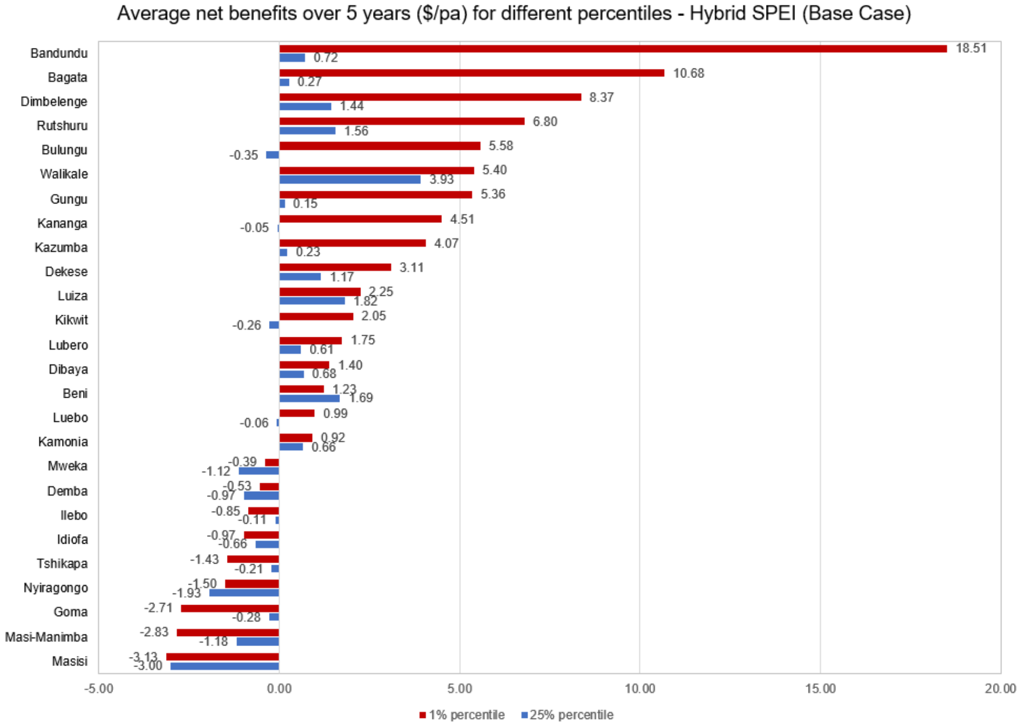
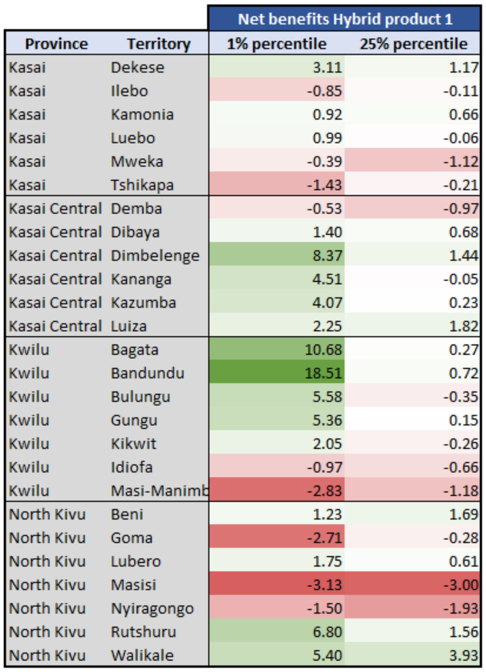


Figure 31: Net benefits average over 5 years against unprotected revenue, Hybrid structures
Source: *AXA Climate*

Both hydrid structures have similar net benefits distribution amongst revenues, with a comparable profitability point (roughly 30% percentile). The hybrid structure based on SPEI however seems more cost-efficient as its net benefits are higher for the tails of revenues distribution (high and low percentiles). The SMI hybrid structure have higher net benefits in the middle of revenues' distribution (percentiles between 25% and 75%).

Although the aggregate view is interesting, it might be worth to study the efficiency of the hybrid covers at territory granularity (for SPEI) and at province granularity (to compare SPEI and SMI). The 1% percentile net benefits is not the most relevant metric here, contrarily to what have been done for parametric insurance. Indeed, the insurance alone aims at protecting such rare events. The hydrid cover however should protect more events, with return periods starting from 5 years. To have a more accurate view of the efficiency of the hybrid structure, it is thus possible to compute the 1% percentile net benefits as well as the 25% percentile net benefits, by territory (and province). Figure 32 below shows results for SPEI based hybrid structure at territory level.





		Net benefits Hybrid product 1	
Province	**Territory**	**1% percentile**	**25% percentile**
Kasai	Dekese	3.11	1.17
Kasai	Ilebo	-0.85	-0.11
Kasai	Kamonia	0.92	0.66
Kasai	Luebo	0.99	-0.06
Kasai	Mweka	-0.39	-1.12
Kasai	Tshikapa	-1.43	-0.21
Kasai Central	Demba	-0.53	-0.97
Kasai Central	Dibaya	1.40	0.68
Kasai Central	Dimbelenge	8.37	1.44
Kasai Central	Kananga	4.51	-0.05
Kasai Central	Kazumba	4.07	0.23
Kasai Central	Luiza	2.25	1.82
Kwilu	Bagata	10.68	0.27
Kwilu	Bandundu	18.51	0.72
Kwilu	Bulungu	5.58	-0.35
Kwilu	Gungu	5.36	0.15
Kwilu	Kikwit	2.05	-0.26
Kwilu	Idiofa	-0.97	-0.66
Kwilu	Masi-Manimb	-2.83	-1.18
North Kivu	Beni	1.23	1.69
North Kivu	Goma	-2.71	-0.28
North Kivu	Lubero	1.75	0.61
North Kivu	Masisi	-3.13	-3.00
North Kivu	Nyiragongo	-1.50	-1.93
North Kivu	Rutshuru	6.80	1.56
North Kivu	Walikale	5.40	3.93

Figure 32: 5 year average 1% and 25% percentile net benefits per territory, Hybrid product 1 (SPEI)
Source: AXA Climate

It is logical to have a smaller net benefit for the 25% percentile than for the 1% percentile, since the cover by territory protects against the 20% worst events. However, Figure 32 shows that **all territories that have a negative net benefit at 1% percentile also have a negative 25% percentile net benefit**. This means these territories are not covered enough, or that the Hybrid product 1 based on SPEI is not adapted to their risk. **This concerns 9 territories out of 26**, *i.e.* roughly a third. In order to ensure that there is no underlying spatial clustering of negative benefits, it is possible to show the 1 percent net benefits on a map (see Figure 33 below). This map shows that the territories showing negative net benefits at the 1 percent percentile for the SPEI-based Hybrid structure are not particularly clustered. On the contrary, is seems quite spread across the country and provinces.

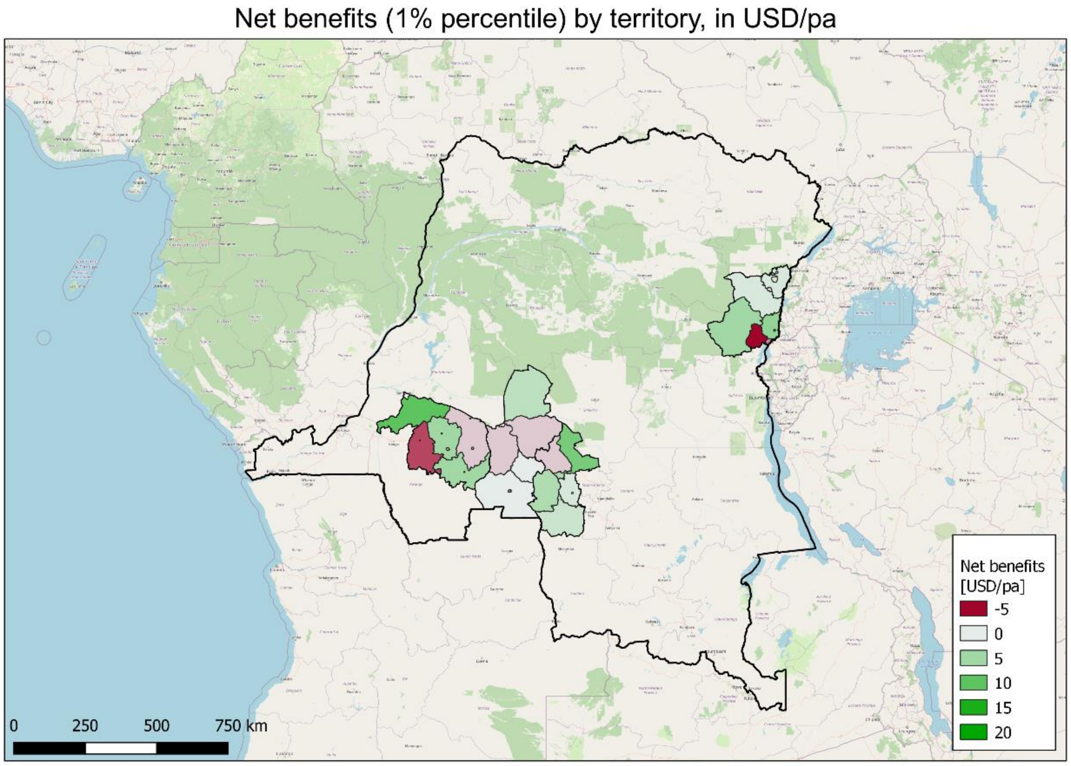
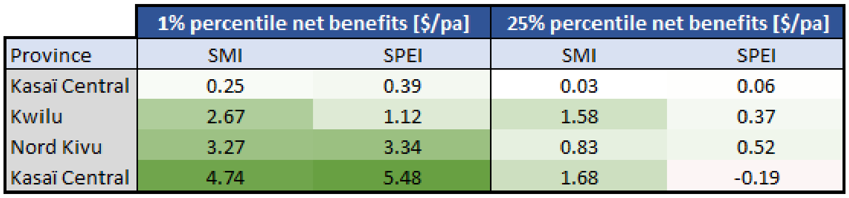


Figure 33: Net Benefits at the 1% percentile for Hybrid structure 1 (SPEI), by territory
Source: AXA Climate

The same analysis on the province level allows to compare Hybrid structures 1 (SPEI) and 2 (SMI). The following table gathers the 1% and 25% percentiles net benefits at province level.



	1% percentile net benefits [$/pa]		25% percentile net benefits [$/pa]	
Province	SMI	SPEI	SMI	SPEI
Kasaï Central	0.25	0.39	0.03	0.06
Kwilu	2.67	1.12	1.58	0.37
Nord Kivu	3.27	3.34	0.83	0.52
Kasaï Central	4.74	5.48	1.68	-0.19

Table 20: 5 year average 1% and 25% percentile net benefits per province, Hybrid structure 1 (SPEI) and 2 (SMI)
Source: AXA Climate

Table 20 shows that for the 1% percentile, as for the parametric insurance alone, Hybrid structure 1 based on SPEI brings more disparity to net benefits per province than Hybrid structure 2 based on SMI. Additionally, he results on the 25% percentile show that Hybrid product 2 offers more effective cover around this risk layer.

Key takeaways of the Cost-Benefit Analysis:

- A Standalone reserve seems more appropriate than an Insured reserve, for both indices;
- Hybrid product 1 (SPEI) has less basis risk than Hybrid product 2 (SMI), thanks to its payout at *crop x territory* level;
- However, one third of territories have a cover deficiency with Hybrid product 1 (SPEI);
- Hybrid product 2 (SMI) has less disparity between provinces net benefits than Hybrid product 1;
- There is a strong complementarity between parametric insurance and the Reserve to cover up to 20 % percentile risks at country level.

Note: These analyses were made for the Base Case. The sensitivities analysis presented in the next section do not alter the general products comparison. They merely enable to assess how net benefits vary, for chosen hybrid products, under different scenarios.

3. Sensitivity analysis

a. Scenario definition

While subsection **4.2.** defined the different sensitivities categories, this subsection defines precisely each sensitivity scenario.

Climate change

The “Base Case” relied on the assumption of the absence of trend for yield and index due to climate change. As this is unlikely, even though this study is made for rather short term, some trends for yield and index (SPEI and SMI) will be established.

The yield projection is based on CARD tool[7], at the whole country level. In order to have more robustness of the yield projection, yield projection for cassava and maize were also retrieved from the ISIMIP repository[8] (CLM4.5 model for maize and LPJML for cassava). This enables comparison between models, since these different yield are projected thanks to underlying agricultural models, based on temperature and precipitations projections.

These data show that, according to models, there is no projected change in standard deviation for cassava and maize yield in DRC. This being said, the average yield level itself is expected to change, depending on the models and the scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). Figure 34 below shows relative evolution of cassava and maize yield in DRC, relatively to 2021 yield.

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[7] Available at: https://www.ifad.org/en/web/knowledge/-/publication/climate-adaptation-in-rural-development-card-assessment-tool

[8] Available at: https://data.isimip.org

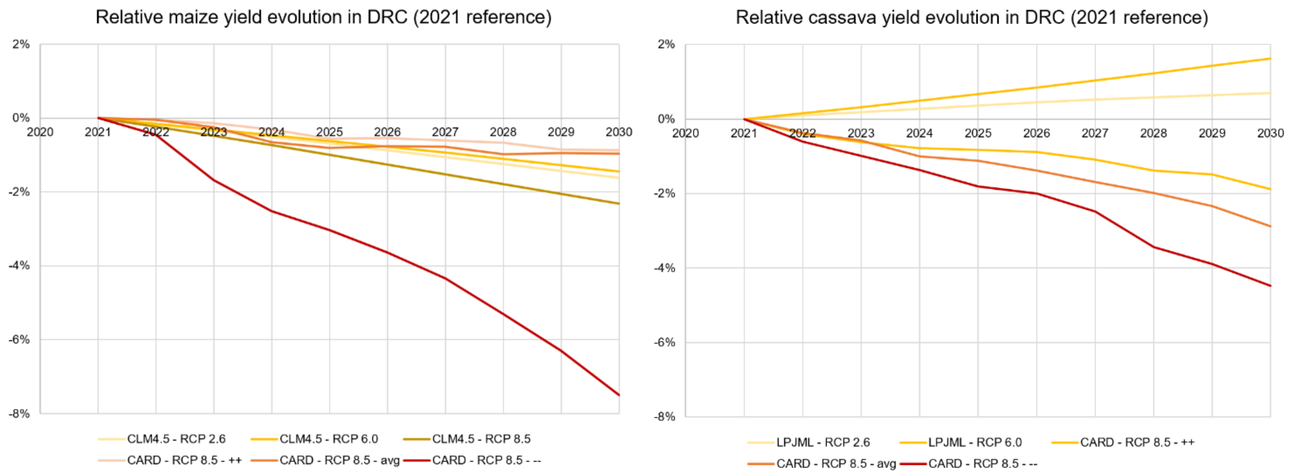


Figure 34: Relative evolution of cassava and maize yield in DRC, for different models and scenarios
<u>Source</u>: AXA Climate

CARD database provides three different scenarios based on RCP8.5 projection: an average scenario ("avg"), an optimistic scenario ("++") and a pessimistic scenario ("- -"). Other models (LPJML and CLM4.5 for cassava and maize respectively) provide projections as well, for RCP2.6 to RCP8.5.

For **maize projections**, the following scenario choices have been made:

- *For the "optimistic" scenario*, four models are very close to the same trend (CARD RCP8.5 optimistic, CARD RCP8.5 average, CLM45 RCP2.6 and CLM4.5 RCP6.0). Picking one of them therefore seems to be a good choice for the "optimistic" scenario. The CARD RCP8.5 optimistic scenario was thus selected as "optimistic" scenario.
- *For the "pessimistic" scenario*, variations between scenarios were very strong, notably between CARD RCP8.5 pessimistic and CLM4.5 RCP8.5. Even though the latter seems a bit more reasonable, it was deemed logical to choose the CARD RCP8.5 pessimistic view since this is a "pessimistic" scenario and not a best estimate. This also allows to stay within the same family of models to ensure consistency.

For **cassava projections**, the following choices have been made:

- *For the "optimistic" scenario*, as LPJML models gives surprising results, it was decided to stay consistent with the maize scenario and select the CARD RCP8.5 optimistic projection for our "optimistic" scenario.
- *For the "pessimistic" scenario*, consistency motivates us to chose the CARD RCP8.5 pessimistic view as well.

It is more challenging to find projection for the indices, to the extent that there is no "off the shelf" model that directly gives estimation of projected SPEI or SMI. For the SPEI, Water Balance was used as a proxy. Multi-model projections (RCP4.5 and RCP 8.5) of rainfall and temperature were retrieved, which give us annual average temperature and annually cumulated rainfall. A regression model was built to find a formula that links directly the index (SPEI or SMI) to these variables:

$$Index_{province,t} = \alpha T_{province,t} + \beta R_{province,t} + \delta$$

where $\left(T_{province,t}\right)_t$ is the timeseries of annual average temperature for a given province, and $\left(R_{province,t}\right)_t$ is the annually cumulated rainfall timeseries. Historical values from ERA5 were used to build the index and the variables from 1980. The regression coefficients α, β and δ were estimated and used to deduce the expected index value for future years (2030, 2035 and 2050). This enables to estimate an average trend by interpolating, in order to predict future value of the index.

This method gives acceptable results since correlation between index and our variables is very good. Indeed, SPEI is derived from water balance and SMI is derived from soil moisture, both being highly correlated to precipitations and temperature, even when studied at annual level. The challenge, however, is that projections seem consistent with historical trend for temperature, whereas it does not for rainfall. The example of Kasaï Central province is displayed in Figure 35 below, but this is also true for Kasaï and Kwilu. Only Nord Kivu does not have this difference.

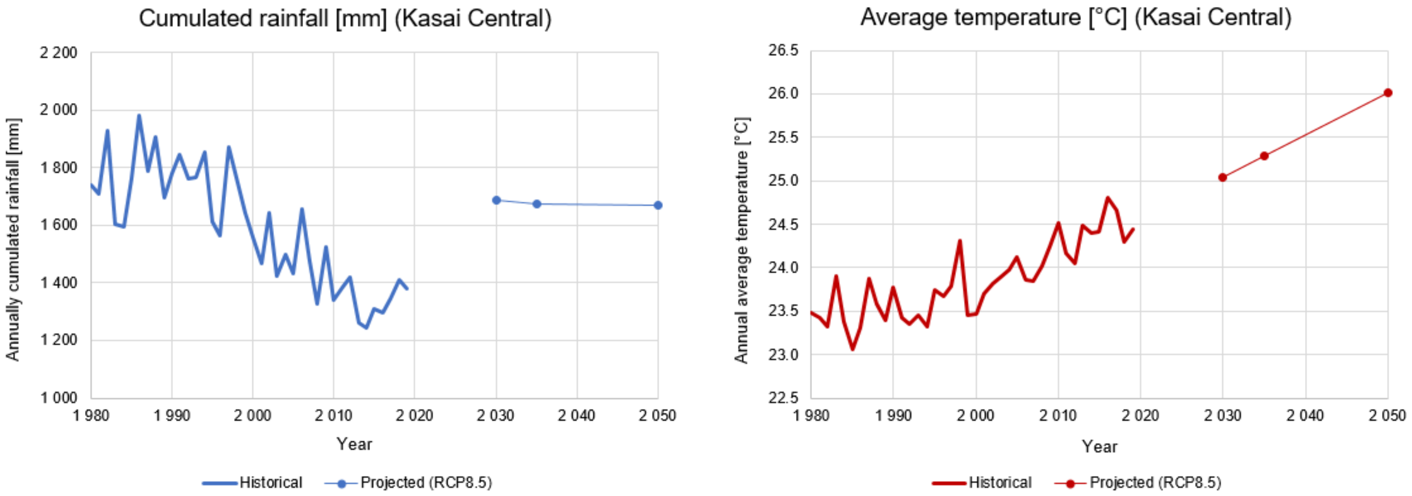


Figure 35: Historical and projected variables (RCP8.5) for Kasaï Central province
<u>Source</u>: Historical data from ERA5 and projected data from CMIP5

This historical “trend” on rainfall seems uncompatible with projected rainfall levels. It is very unreliable to project climatic variables from historical “trends”. In the case of DRC, the rainfall decrease over 20 years can be the effect of a macro level variability which doesn’t correspond to an actual trend. Moreover, for last years, the trend seems to flatten, and it could very well increase again to go back to 1,700 mm of annual precipitations (see Figure 36 below):

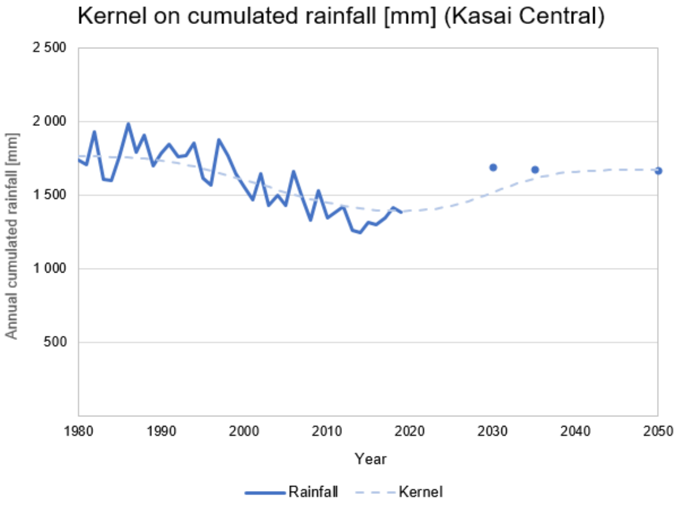


Figure 36: Kernel regression on annual precipitation, historical and projected, Kasaï Central
<u>Source</u>: AXA Climate

This illustrative graph shows that the difference of trend (historical decrease vs flat projections) is not necessarily incompatible. In case of conflict between historical trend and model projection, trust should go to models – all the more that there is a global consistency of prediction that drought risk in Central Africa is not likely to worsen (*cf.*

IPCC [2021]). Extreme weather risk on the other hand (extreme temperatures and extreme precipitations) is expected to increase with high level of confidence.

It is to be noted that, regardless of the accuracy of projections, the insurance market tends to be more conservative than climatologists. The "optimistic" scenario will thus reflect the view of climatologists, while the "pessimistic" scenario will reflect the conservative approach of insurers. The latter are most likely to estimate projections based on historical trend (last 20 to 30 years) for their pricing.

Performance

Productivity improvement performance – The Base Case scenario already reflected the non-performance hypothesis of the productivity improvement package. The performance of the package is based on Client projection of a 200% production improvement for maize, and a 70% improvement for cassava over 10 years. With an hypothesis of constant annual improvement, this can be converted into a 11.61% annual production improvement for maize and a 5.45% annual production improvement for cassava. This is the selected "Package performance" scenario.

Index performance – Aside from the Base Case (unrealistic) assumption of a 100% correlation between index, three different sensibilities to index performance have been performed for each index: a non-performance scenario, a performance scenario and a high performance scenario.

It is difficult to define a "performance" and a "non-performance" scenario for the index as we have not enough data in DRC (or even in neighbouring countries) to estimate accurately the correlation between index and yield. The Base Case was built around a perfect correlation, which is unrealistic but gives insight on how the covers could impact the protected revenues if the correlation is verified in practice.

Different sources pointed out that a rainfall based index, with little information on crop location, calendar, soil caracteristics and topology, could have a correlation with yield ranging from 20% to 50%. We have been able to gather some territory level maize yield data in several Czech Republic and Romania. These countries are obviously very different from DRC, both in terms of climate and in terms of development. We however think this can be of interest. We calculated the water balance, as proxy of SPEI, based on ERA5 data (*i.e.* precipitation minus potential evaporation) and accumulated it during crop development period.

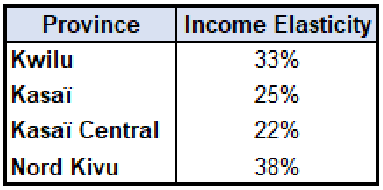
Average historical correlation in Romania betweeen aggregated water balance (SPEI before standardization) and yield at territory level is 22%, and 45% in Czech Republic. Although we have no clear explanation for the difference of correlation between these two countries, we can see that it gives credit to our external sources estimation of a correlation ranging from 40% to 20%. We then consider that a performing SPEI index reaches a 40% correlation with yield for a given crop and territory, while a non-performance scenario will be based on a 20% correlation.

The same work was performed with ERA5 Soil Moisture data: the SMI was built back and compared, at territory level, to local maize yields. Average historical correlation in Romania between SMI and yield at territory level is 40%, and 58% in Czech Republic. We can see that correlation ranges from 60% to 40%. We then consider that a performing SMI index reaches a 60% correlation with yield for a given crop and territory, while a non-performance scenario will be based on a 40% correlation.

On the request of Client, a "High Performance" scenario of 80% correlation has been added. However, such a correlation is extremely unlikely to occur in practice.

Economics

Price elasticity to yield – The Base Case assumed no price reaction ("elasticity") to yield shock, meaning that farmer's revenue from yields were directly given by the formula indicated section **4.1.a**. Prefeasibility study yet dived into economic dynamics of DRC and showed that there is a strong income elasticity to yields (Table 21). Table 21 values are used in our sensitivity scenarios.



Province	Income Elasticity
Kwilu	33%
Kasaï	25%
Kasaï Central	22%
Nord Kivu	38%

Table 21: Income elasticity to yield
<u>Source</u>: *Prefeasibility study*

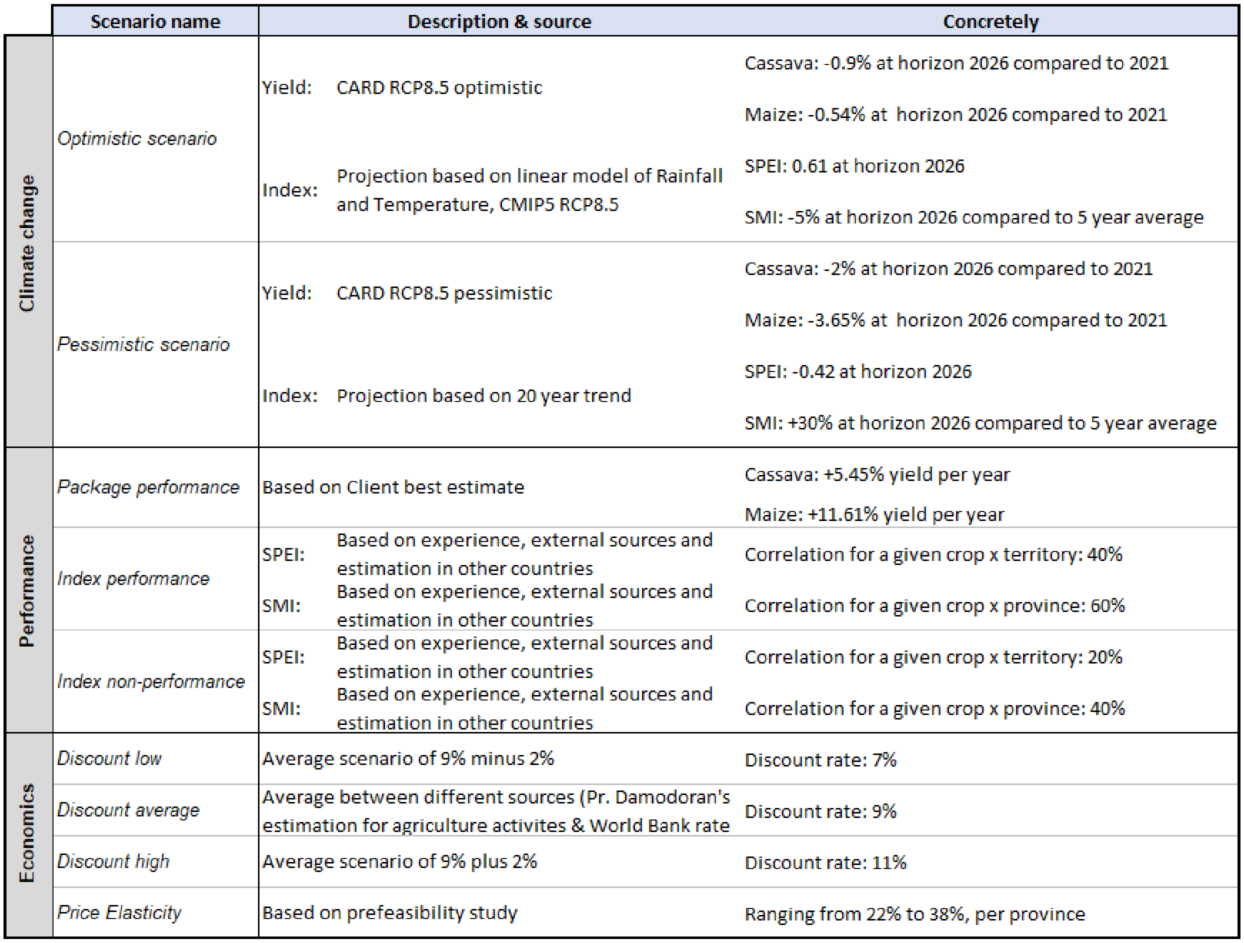
For the Kasaï example, a 10% drop in yield only causes a 3.3% drop in revenue, due to price increase. This is due to the fact that infrastructures are not completely developed in DRC, which means that a local yield shock causes prices to increase as offer decreases, which mitigates the income loss.

Discount rate – The discount rate has an impact on the present value of future cash-fows. As such, it is likely to impact the total estimated net benefits. There was no discount rate in the Base Case, however we will introduce three possible discount rates as sensitivities:

- We will use a discount rate at 9% as central scenario. This rate is an average between Pr. Damodaran's discount rate estimation for farming and agriculture activities in countries that are closest to DRC in terms of systemic risk (6%), and the 12% discount rate used by the Client in DRC for internal modelling to account for the "social rate of return on projects not funded due to reallocation of budgets";
- A "High" scenario of 11% discount rate;
- A "Low" scenario at 7% discount rate.

Recap of the sensitivity hypothesis

Table 22 offers a recap of the different hypothesis made for sensitivity scenario definition.



	Scenario name	Description & source		Concretely
Climate change	*Optimistic scenario*	Yield:	CARD RCP8.5 optimistic	Cassava: -0.9% at horizon 2026 compared to 2021 Maize: -0.54% at horizon 2026 compared to 2021
		Index:	Projection based on linear model of Rainfall and Temperature, CMIP5 RCP8.5	SPEI: 0.61 at horizon 2026 SMI: -5% at horizon 2026 compared to 5 year average
	Pessimistic scenario	Yield:	CARD RCP8.5 pessimistic	Cassava: -2% at horizon 2026 compared to 2021 Maize: -3.65% at horizon 2026 compared to 2021
		Index:	Projection based on 20 year trend	SPEI: -0.42 at horizon 2026 SMI: +30% at horizon 2026 compared to 5 year average
Performance	*Package performance*	Based on Client best estimate		Cassava: +5.45% yield per year Maize: +11.61% yield per year
	Index performance	SPEI:	Based on experience, external sources and estimation in other countries	Correlation for a given crop x territory: 40%
		SMI:	Based on experience, external sources and estimation in other countries	Correlation for a given crop x province: 60%
	Index non-performance	SPEI:	Based on experience, external sources and estimation in other countries	Correlation for a given crop x territory: 20%
		SMI:	Based on experience, external sources and estimation in other countries	Correlation for a given crop x province: 40%
Economics	*Discount low*	Average scenario of 9% minus 2%		Discount rate: 7%
	Discount average	Average between different sources (Pr. Damodoran's estimation for agriculture activites & World Bank rate		Discount rate: 9%
	Discount high	Average scenario of 9% plus 2%		Discount rate: 11%
	Price Elasticity	Based on prefeasibility study		Ranging from 22% to 38%, per province

Table 22: Sensitivy scenarios definition
Source: AXA Climate

b. Results

Previous subsections enabled to select the standalone reserve over the insured reserve, and to define sensitivity scenarios. For each sensitivity, we modify the Base Case to take into account the change of scenario. The following table (Table 23) displays all results.

Each line of the Table shows the difference between the Base Case and the results of the scenario. The results thus show the marginal impact of each sensitivity to the Base Case, as a delta. The CBA hypothesis is that different sensitivities work linearly with each other. This means that, to estimate a more complex scenario that encompasses both pessimistic climate change and package performance (for instance), it is possible to sum the marginal deviations of each scenario.

Scenario / instrument		Annual Costs *(USD/pa)*					Annual Benefits *(USD/pa)* Revenue protected – Revenue unprotected					Annual Net Benefits *(USD/pa)* Benefits - Costs				
		1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile
Base Case - SPEI		6.16	6.16	6.16	6.16	6.16	12.54	3.93	1.89	1.20	1.83	6.38	-2.23	-4.26	-4.96	-4.33
Climate change	*Optimistic scenario*	-3.57	-3.57	-3.57	-3.57	-3.57	-5.10	-2.58	-1.20	-0.66	-0.90	-1.53	0.99	2.36	2.90	2.67
	Pessimistic scenario	5.93	5.93	5.93	5.93	5.93	4.34	4.31	3.31	1.91	1.13	-1.59	-1.62	-2.61	-4.01	-4.79
Performance	*Package performance*	-	-	-	-	-	8.15	9.01	9.71	10.59	12.95	8.15	9.01	9.71	10.59	12.95
	Index high-performance	-0.04	-0.04	-0.04	-0.04	-0.04	-4.29	0.29	1.00	0.37	-1.69	-4.25	0.33	1.03	0.41	-1.65
	Index performance	-0.07	-0.07	-0.07	-0.07	-0.07	-9.17	-0.71	1.11	1.71	0.97	-9.09	-0.64	1.18	1.78	1.04
	Index non-performance	0.12	0.12	0.12	0.12	0.12	-10.30	-1.27	1.05	2.31	3.86	-10.42	-1.38	0.93	2.19	3.75
Economics	*Discount 7%*	-1.10	-1.10	-1.10	-1.10	-1.10	-0.59	-0.88	-0.55	-0.30	-0.30	0.50	0.22	0.55	0.80	0.80
	Discount 9%	-1.35	-1.35	-1.35	-1.35	-1.35	-0.75	-1.10	-0.65	-0.35	-0.38	0.61	0.26	0.70	1.00	0.97
	Discount 12%	-1.59	-1.59	-1.59	-1.59	-1.59	-0.94	-1.30	-0.74	-0.41	-0.47	0.65	0.29	0.85	1.18	1.12
	Price Elasticity	-	-	-	-	-	-9.15	-1.49	0.34	1.44	11.56	-9.15	-1.49	0.34	1.44	11.56
Base Case - SPEI Standalone Reserve		0.44	0.64	0.81	1.00	1.35	4.33	3.86	1.66	1.00	1.06	3.88	3.22	0.85	0.00	-0.29
Climate change	*Optimistic scenario*	0.02	0.24	0.30	0.25	0.06	1.71	-2.20	-0.84	-0.28	-0.29	1.70	-2.44	-1.14	-0.53	-0.35
	Pessimistic scenario	-0.01	-0.09	-0.15	-0.20	-0.14	-1.89	1.37	1.29	0.58	0.04	-1.88	1.47	1.43	0.79	0.18
Performance	*Package performance*	-	-	-	-	-	9.14	11.11	12.01	13.02	15.82	9.14	11.11	12.01	13.02	15.82
	Index high-performance	-0.01	-0.01	0.00	0.03	0.03	1.70	0.80	2.29	2.43	2.27	0.82	-0.46	0.67	0.39	-0.46
	Index performance	-0.01	0.00	0.00	0.04	0.03	-1.26	-1.14	0.79	1.20	0.71	-1.25	-1.14	0.79	1.17	0.67
	Index non-performance	-0.01	-0.01	0.00	0.03	0.03	-1.91	-1.52	0.90	1.52	1.33	-1.90	-1.51	0.90	1.49	1.30
Economics	*Discount 7%*	-0.04	-0.07	-0.10	-0.15	-0.24	-0.61	-0.59	-0.30	-0.19	-0.20	-0.57	-0.52	-0.20	-0.04	0.04
	Discount 9%	-0.05	-0.09	-0.13	-0.18	-0.29	-0.76	-0.72	-0.36	-0.23	-0.25	-0.71	-0.64	-0.23	-0.04	0.05
	Discount 12%	-0.06	-0.11	-0.15	-0.22	-0.34	-0.92	-0.87	-0.43	-0.26	-0.28	-0.86	-0.76	-0.28	-0.04	0.06
	Price Elasticity	-	-	-	-	-	-0.69	-0.71	0.79	0.83	0.17	-0.69	-0.71	0.79	0.83	0.17
Base Case - SMI		5.91	5.91	5.91	5.91	5.91	10.65	4.22	2.47	1.19	0.09	4.74	-1.69	-3.44	-4.72	-5.82
Climate change	*Optimistic scenario*	-0.78	-0.78	-0.78	-0.78	-0.78	-0.83	-0.54	-0.44	-0.26	-0.02	-0.04	0.24	0.35	0.52	0.77
	Pessimistic scenario	13.47	13.47	13.47	13.47	13.47	8.64	8.53	7.85	6.72	1.52	-4.83	-4.94	-5.62	-6.75	-11.94
Performance	*Package performance*	-	-	-	-	-	8.28	9.46	10.09	10.85	13.48	8.28	9.46	10.09	10.85	13.48
	Index high-performance	0.03	0.03	0.03	0.03	0.03	-3.52	-0.32	0.37	0.70	0.17	-3.55	-0.35	0.34	0.67	0.13
	Index performance	0.03	0.03	0.03	0.03	0.03	-5.85	-0.76	0.44	1.40	1.69	-5.87	-0.79	0.41	1.38	1.66
	Index non-performance	-0.10	-0.10	-0.10	-0.10	-0.10	-7.63	-1.49	0.28	1.82	3.96	-7.53	-1.39	0.38	1.92	4.06
Economics	*Discount 7%*	-1.05	-1.05	-1.05	-1.05	-1.05	-0.13	-0.62	-0.74	-0.59	-0.01	0.92	0.44	0.31	0.46	1.04
	Discount 9%	-1.30	-1.30	-1.30	-1.30	-1.30	-0.18	-0.78	-0.93	-0.67	-0.01	1.12	0.52	0.37	0.63	1.29
	Discount 12%	-1.53	-1.53	-1.53	-1.53	-1.53	-0.29	-0.99	-1.10	-0.73	-0.01	1.23	0.54	0.43	0.79	1.52
	Price Elasticity	-	-	-	-	-	-8.25	-2.39	-0.69	1.15	20.43	-8.25	-2.39	-0.69	1.15	20.43
Base Case - SMI Standalone Reserve		0.41	0.63	0.84	1.14	1.42	3.70	3.76	1.84	0.87	0.37	3.29	3.13	1.00	-0.27	-1.05
Climate change	*Optimistic scenario*	-	0.03	0.05	0.08	-	0.39	-0.43	-0.30	-0.07	-0.05	0.38	-0.45	-0.35	-0.15	-0.05
	Pessimistic scenario	-0.03	-0.16	-0.26	-0.43	-0.19	-2.08	1.67	2.89	2.16	0.25	-2.06	1.83	3.15	2.60	0.44
Performance	*Package performance*	-	-	-	-	-	9.32	11.52	12.45	13.54	16.52	9.32	11.52	12.45	13.54	16.52
	Index high-performance	-	-	-	-	-	0.98	0.75	2.06	2.74	3.00	0.15	-0.51	0.38	0.47	0.17
	Index performance	-	-	-	-	-	0.60	0.34	2.22	3.33	3.44	-0.22	-0.93	0.54	1.05	0.60
	Index non-performance	-	0.01	0.01	0.01	-	0.10	-0.13	2.08	3.59	4.31	-0.73	-1.40	0.39	1.31	1.47
Economics	*Discount 7%*	-0.04	-0.07	-0.11	-0.18	-0.26	-0.40	-0.51	-0.35	-0.15	-0.10	-0.37	-0.44	-0.24	0.03	0.16
	Discount 9%	-0.04	-0.09	-0.14	-0.22	-0.31	-0.55	-0.65	-0.44	-0.18	-0.13	-0.50	-0.56	-0.30	0.05	0.18
	Discount 12%	-0.05	-0.10	-0.16	-0.26	-0.37	-0.64	-0.78	-0.51	-0.22	-0.16	-0.59	-0.67	-0.34	0.05	0.21
	Price Elasticity	-	-	-	-	-	-1.34	-1.08	0.54	1.23	0.73	-1.34	-1.08	0.54	1.23	0.73

Table 23: Sensitivity scenarios marginal impact on Base Case, SMI and SPEI, parametric insurance and standalone reserve

Source: AXA Climate

Several observations can be made from this chart:

- Package productivy performance has a tremendous impact on net benefits. This is due to the fact that yield improvement is only taken into account for protected revenues, since only farmers buying the agriculture development pack are covered by insurance. This high net benefit increase (nearly $10/farmer) is only due to the increase of yield for protected farmers.
- Discounting logically tends to reduce future costs and benefits to bring them back to their net present value.
- Climate change "optimistic" scenario reduces costs, because it decreases risk which in turn causes premium to decrease. It also reduces benefits as payouts become less frequent. The overall impact on net benefits is slightly positive. However, this is rather theoretical as it is very unlikely that insurers will take into account the positive effect of climate change to reduce the premium.
- Climate change "pessimistic" scenario works the other way around. It increases costs, because it increases risk which in turn raises the level of the premium. It also logically increases benefits, but on overall this has a negative impact over net benefits.
- Non-performance, performance and high performance scenarios drastically impact the efficiency of the cover. This is a fundamental result of the study. The base case assumed (unrealistically) a perfect correlation (100%) between index and yield. In this context, the insurance product showed a net benefit to farmers for the 10% percentile of the revenues distribution. However, this result changes dramatically when the correlation assumption is realistically revised. Whether with 40% correlation (non-performance scenario), 60% (performance scenario) or 80% (high performance scenario), the benefit of insurance becomes negative for more than the 90% worst revenues. This is due to the very large number of false positives (i.e. when payouts are triggered whereas yield is high), which considerably increases the cost of insurance. This explains why net benefits decrease for low percentiles and increase for high percentiles. It is even more true for the SMI cover (parametric insurance and standalone reserve) than for the SPEI, because the payout is made at province level instead of territory level. The SPEI cover enables to add small mismatches between payout and yield (because there are 26 territories and 2 crops, *i.e.* 52 different indexes to be calculated each year) whereas SMI triggers at province level (4 provinces and 2 crops, *i.e.* 8 indexes only). A mismatch for SMI causes a big error, whereas the same mismatch for SPEI has less effect overall because it only happens at territory level.
- Income elasticity to yield has a strong effect on net benefits. It is interesting to note, however, that the impact on net benefits is much more severe for parametric insurance than for standalone reserve. The elasticity has the same effect as non-performance: it reduces net benefits around the 1% percentile and shifts it towards higher percentiles. This is an unexpected effect of elasticity: because it has a linear relationship with yield, it should not change the rank of income in the simulation, and the correlation is supposed to stay unchanged. We can ensure that by comparing unprotected revenues per farmer with elasticity to unprotected revenue per farmer without elasticity. Adding the payouts to the graph should enable to verify visually that payouts still occur when revenues are low. The following figure (Figure 37) shows simulated revenues for Parametric insurance Design 2 (based on SMI) for year 1 and year 5. The graph would be similar for SPEI based insurance cover.

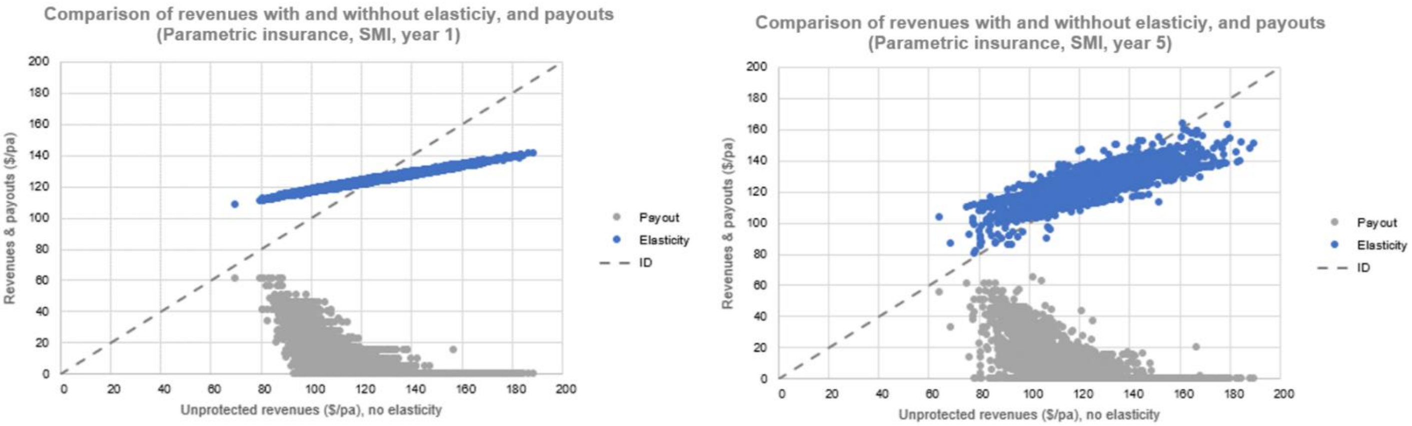


Figure 37: Revenues ($/pa) with and without elasticity, with payouts (SMI parametric cover) for year 1 (left diagram) and year 5 (right diagram)
<u>Source</u>: *AXA Climate*

Figure 37 shows that the relationship between revenues and revenues taking into account income elasticity (blue points) is linear. Some noise appear for year 5, which is due to the fact that farmers who get a payout during their first year of coverage are excluded for the scheme. This causes superficies to be a variable, which changes from one simulation to the other. The relative contribution of a given province to the aggregate revenue can thus change from one simulation to the other. Since elasticity rate depends on province, this means the average elasticity rate changes as well, which explains why the regression is less accurate for year 5 (during which superficies change depending on payouts simulated for year 4) than for year 1, where superficies are constant.

Because the relation between revenues with and without elasticity is linear, correlation between revenues and yield does not change. This does not explain the surprising results of income elasticity for net benefits.

What Figure 37 shows, however, is that elasticity reduces the volatility of revenues. Indeed, for year 1, revenues are ranged from $90/farmer to $160/farmer. Elasticity decreases revenues when it is high and increases it when it is low, because of crop price variation inversed to yield shock. For year 1, unprotected revenues range from $115/farmer to $135/farmer, which divides the interval by three. If we look at revenues distribution (protected and unprotected, still for parametric Design 2), we find the following (Figure 38):

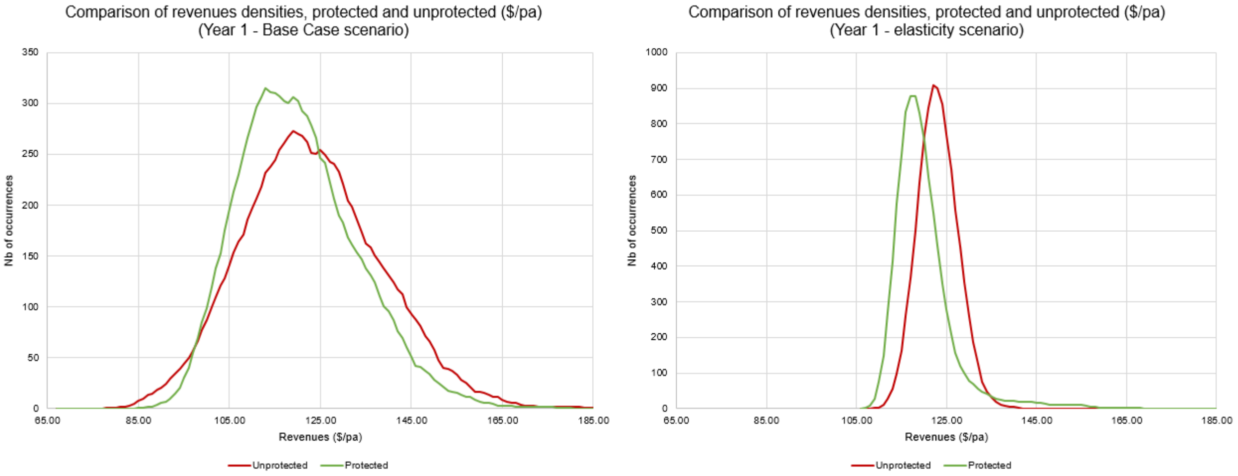


Figure 38: Revenue distributions ($/pa), protected and unprotected, with and without elasticity
<u>Source</u>: *AXA Climate*

Figure 38 shows what was intuited from Figure 37, *i.e.* that revenues' spread less with elasticity, and concentrate more around its average value. It is striking that, with elasticity (right graph), protected revenues have a heavier tail than unprotected revenues. This means that the insurance premium is too high compared to the distribution of revenues with price elasticity.

This is a similar issue as was noticed for territories with parametric Design 1 and Kasaï province for parametric Design 2: payouts are too high compared to revenues. Here payouts actually change worst years into best years, in terms of revenues. The premium is thus very high compared to the revenues, which explains that the cover does not offer optimal protection. It would be much more interesting for farmers, in this case, to have a cover that triggers more often with a smaller payout: the premium would be the same except there would be more frequent compensation with a more reasonable amount.

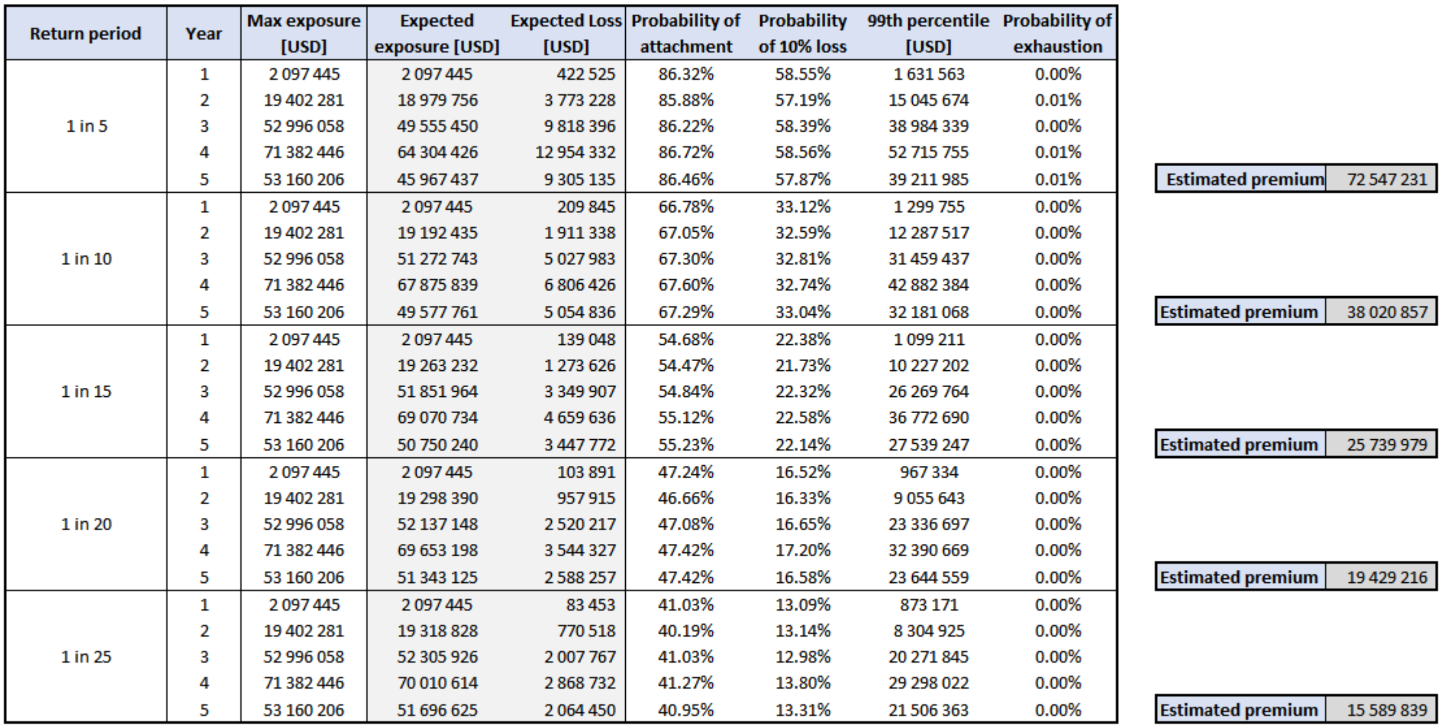
4. Parametric Design 3

Based on the learning of the cost-benefit analysis, the goal of Parametric Design 3 is to combine the best of the two previous designs. On the one hand, the territory level trigger from Parametric Design 1 (SPEI) coverage is kept, as cost-benefit analysis shows it reduces basis risk. On the other hand, a differentiated limit per crop (which better reflects the distribution of farmers' incomes) and the soil moisture index (which is easier to calculate and is likely to be better correlated with yields) are introduced from Parametric Design 2.

Parametric Design 3 thus tries to gather characteristics that would probably enable to build an optimal cover:

- Trigger based on a Soil Moisture Index (SMI);
- Payout calculated for each crop *x* territory;
- Trigger threshold set at crop *x* territory granularity;
- Differentiated limit per crop.

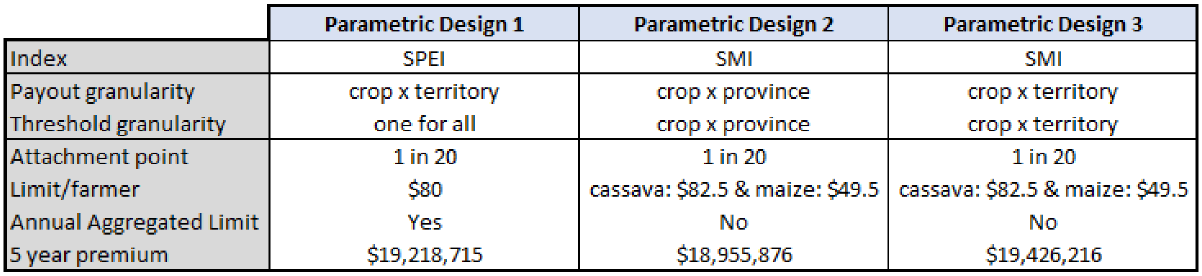
The cover metrics for different return period triggers are displayed in Table 24 below:



Return period	Year	Max exposure [USD]	Expected exposure [USD]	Expected Loss [USD]	Probability of attachment	Probability of 10% loss	99th percentile [USD]	Probability of exhaustion		
1 in 5	1	2 097 445	2 097 445	422 525	86.32%	58.55%	1 631 563	0.00%		
	2	19 402 281	18 979 756	3 773 228	85.88%	57.19%	15 045 674	0.01%		
	3	52 996 058	49 555 450	9 818 396	86.22%	58.39%	38 984 339	0.00%		
	4	71 382 446	64 304 426	12 954 332	86.72%	58.56%	52 715 755	0.01%		
	5	53 160 206	45 967 437	9 305 135	86.46%	57.87%	39 211 985	0.01%	Estimated premium	72 547 231
1 in 10	1	2 097 445	2 097 445	209 845	66.78%	33.12%	1 299 755	0.00%		
	2	19 402 281	19 192 435	1 911 338	67.05%	32.59%	12 287 517	0.00%		
	3	52 996 058	51 272 743	5 027 983	67.30%	32.81%	31 459 437	0.00%		
	4	71 382 446	67 875 839	6 806 426	67.60%	32.74%	42 882 384	0.00%		
	5	53 160 206	49 577 761	5 054 836	67.29%	33.04%	32 181 068	0.00%	Estimated premium	38 020 857
1 in 15	1	2 097 445	2 097 445	139 048	54.68%	22.38%	1 099 211	0.00%		
	2	19 402 281	19 263 232	1 273 626	54.47%	21.73%	10 227 202	0.00%		
	3	52 996 058	51 851 964	3 349 907	54.84%	22.32%	26 269 764	0.00%		
	4	71 382 446	69 070 734	4 659 636	55.12%	22.58%	36 772 690	0.00%		
	5	53 160 206	50 750 240	3 447 772	55.23%	22.14%	27 539 247	0.00%	Estimated premium	25 739 979
1 in 20	1	2 097 445	2 097 445	103 891	47.24%	16.52%	967 334	0.00%		
	2	19 402 281	19 298 390	957 915	46.66%	16.33%	9 055 643	0.00%		
	3	52 996 058	52 137 148	2 520 217	47.08%	16.65%	23 336 697	0.00%		
	4	71 382 446	69 653 198	3 544 327	47.42%	17.20%	32 390 669	0.00%		
	5	53 160 206	51 343 125	2 588 257	47.42%	16.58%	23 644 559	0.00%	Estimated premium	19 429 216
1 in 25	1	2 097 445	2 097 445	83 453	41.03%	13.09%	873 171	0.00%		
	2	19 402 281	19 318 828	770 518	40.19%	13.14%	8 304 925	0.00%		
	3	52 996 058	52 305 926	2 007 767	41.03%	12.98%	20 271 845	0.00%		
	4	71 382 446	70 010 614	2 868 732	41.27%	13.80%	29 298 022	0.00%		
	5	53 160 206	51 696 625	2 064 450	40.95%	13.31%	21 506 363	0.00%	Estimated premium	15 589 839

Table 24: Key metrics of Parametric Design 3 for different attachment points, at aggregated level
Source: AXA Climate

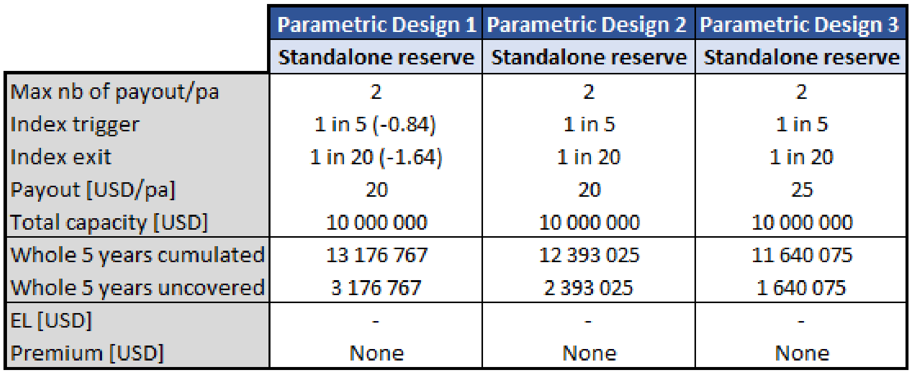
Table 24 shows that without any additional adjustments necessary, Parametric Design 3 reaches the target premium with a 1 in 20 trigger threshold. Settings reflect previous work and are as follows (see Table 25):



	Parametric Design 1	Parametric Design 2	Parametric Design 3
Index	SPEI	SMI	SMI
Payout granularity	crop x territory	crop x province	crop x territory
Threshold granularity	one for all	crop x province	crop x territory
Attachment point	1 in 20	1 in 20	1 in 20
Limit/farmer	$80	cassava: $82.5 & maize: $49.5	cassava: $82.5 & maize: $49.5
Annual Aggregated Limit	Yes	No	No
5 year premium	$19,218,715	$18,955,876	$19,426,216

Table 25: Parametric Designs settings, including new Parametric Design 3
Source: AXA Climate

The reserve for Parametric Design 3 is a Standalone Reserve with the same characteristics as the reserves selected in previous parts (see Table 26), but Parametric Design 3 enables to increase payout per farmer until $25 per farmer, which is interesting compared to the other reserves which only enable a $20 payout.



	Parametric Design 1	Parametric Design 2	Parametric Design 3
	Standalone reserve	Standalone reserve	Standalone reserve
Max nb of payout/pa	2	2	2
Index trigger	1 in 5 (-0.84)	1 in 5	1 in 5
Index exit	1 in 20 (-1.64)	1 in 20	1 in 20
Payout [USD/pa]	20	20	25
Total capacity [USD]	10 000 000	10 000 000	10 000 000
Whole 5 years cumulated	13 176 767	12 393 025	11 640 075
Whole 5 years uncovered	3 176 767	2 393 025	1 640 075
EL [USD]	-	-	-
Premium [USD]	None	None	None

Table 26: Standalone reserve setups, including chosen reserve for Parametric Design 3
Source: AXA Climate

The CBA results for Parametric Design 3, with all sensitivities, are as follows. Each line of the Table shows the difference between Parametric Design 3 Base Case and the results of the scenario. The results thus show the marginal impact of each sensitivity to the Base Case, as a delta.

Scenario / instrument		**Annual Costs** *(USD/pa)*					**Annual Benefits** *(USD/pa)* **Revenue protected – Revenue unprotected**					**Annual Net Benefits** *(USD/pa)* **Benefits - Costs**				
		1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile
Base Case - SMI *(Parametric Design 3)*		5,98	5,98	5,98	5,98	5,98	13,02	4,38	1,99	0,79	0,15	7,03	-1,60	-4,00	-5,19	-5,84
Climate change	*Optimistic scenario*	-0,83	-0,83	-0,83	-0,83	-0,83	-0,83	-0,69	-0,41	-0,15	-0,02	0,00	0,14	0,42	0,68	0,81
	Pessimistic scenario	14,45	14,45	14,45	14,45	14,45	10,44	10,45	8,77	6,00	1,07	-4,01	-4,00	-5,68	-8,45	-13,38
Performance	*Package performance*	-	-	-	-	-	8,26	9,08	9,67	10,51	12,56	8,26	9,08	9,67	10,51	12,56
	Index high-performance	-	-	-	-	-	-5,03	-0,25	0,81	0,75	0,30	-5,04	-0,25	0,80	0,74	0,29
	Index performance	-	-	-	-	-	-7,61	-0,67	1,03	1,60	0,61	-7,61	-0,67	1,03	1,60	0,61
	Index non-performance	-0,04	-0,04	-0,04	-0,04	-0,04	-9,70	-1,20	1,07	2,09	2,25	-9,67	-1,17	1,10	2,13	2,29
Economics	*Discount 7%*	-1,07	-1,07	-1,07	-1,07	-1,07	-0,59	-0,95	-0,64	-0,23	-0,03	0,48	0,12	0,43	0,84	1,04
	Discount 9%	-1,32	-1,32	-1,32	-1,32	-1,32	-0,83	-1,18	-0,76	-0,27	-0,04	0,49	0,15	0,56	1,06	1,29
	Discount 12%	-1,55	-1,55	-1,55	-1,55	-1,55	-1,02	-1,40	-0,86	-0,30	-0,06	0,54	0,16	0,69	1,25	1,50
	Price Elasticity	-	-	-	-	-	-9,28	-1,75	0,36	1,71	11,07	-9,28	-1,75	0,36	1,71	11,07
Base Case - SMI Standalone Reserve *(Parametric Design 3)*		0,88	1,23	1,51	1,97	2,73	3,82	2,16	-0,54	-2,46	-4,46	4,70	3,39	0,98	-0,49	-1,73
Climate change	*Optimistic scenario*	0,02	0,05	0,11	0,15	0,05	0,16	-0,52	-0,36	-0,15	-0,10	0,14	-0,57	-0,47	-0,31	-0,16
	Pessimistic scenario	-0,06	-0,29	-0,48	-0,75	-0,97	-2,62	1,24	2,78	2,32	0,46	-2,56	1,53	3,26	3,07	1,43
Performance	*Package performance*	-	-	-	-	-	11,05	13,38	14,36	15,45	18,47	11,05	13,38	14,36	15,45	18,47
	Index high-performance	-	-	0,01	-	0,01	-0,22	-0,78	0,45	0,63	0,31	-0,23	-0,78	0,45	0,63	0,30
	Index performance	-	-	-	-	0,01	-1,12	-1,17	0,41	1,30	0,87	-1,12	-1,16	0,41	1,30	0,86
	Index non-performance	-	-	0,01	0,01	0,01	-2,29	-1,54	0,44	1,59	1,83	-2,29	-1,54	0,43	1,59	1,83
Economics	*Discount 7%*	-0,08	-0,13	-0,19	-0,29	-0,48	-0,77	-0,70	-0,44	-0,29	-0,23	-0,69	-0,57	-0,26	0,00	0,24
	Discount 9%	-0,10	-0,17	-0,23	-0,36	-0,59	-0,90	-0,87	-0,54	-0,36	-0,28	-0,81	-0,70	-0,30	0,00	0,31
	Discount 12%	-0,12	-0,20	-0,28	-0,42	-0,69	-1,08	-1,03	-0,62	-0,40	-0,33	-0,97	-0,83	-0,34	0,02	0,36
	Price Elasticity	-	-	-	-	-	-1,64	-1,19	0,53	1,27	0,77	-1,64	-1,19	0,53	1,27	0,77

Table 27: CBA results and sensitivity scenarios marginal impact on Base Case, Parametric Design 3
<u>Source</u>: *AXA Climate*

Table 27 notably shows that Parametric Design 3 is less sensitive to a poor index-yield correlation than other Parametric products. This was the goal of this product: improving cover and reducing basis risk. Table 28 offers a comparison between all three parametric designs in terms of sensitivity to index-yield correlation, expressed in absolute terms (not as a delta). In the hypothesis and framework of this CBA, **Parametric Design 3 seems to be the best cover**: under an "Index Performance" scenario (60% correlation), this design still generates $3 of annual net benefits for farmers at the 1% percentile of the revenues distribution, whereas the other designs bring lower ($1.93 for Parametric Design 2) or even negative benefits ($-0.08 for Parametric Design 1).

Scenario / instrument		**Annual Costs** *(USD/pa)*					**Annual Benefits** *(USD/pa)* **Revenue protected – Revenue unprotected**					**Annual Net Benefits** *(USD/pa)* **Benefits - Costs**				
		1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile	1% percentile	25% percentile	50% percentile	75% percentile	99% percentile
Hybrid Design 1	*Index high-performance*	6.56	6.75	6.92	7.15	7.50	13.39	7.61	5.22	2.99	0.77	6.83	0.86	-1.71	-4.16	-6.73
	Index performance	6.52	6.72	6.90	7.12	7.46	5.56	4.67	3.83	3.10	1.87	-0.08	-0.78	-1.45	-2.01	-2.90
	Index non-performance	6.71	6.90	7.08	7.31	7.65	3.77	3.73	3.88	4.02	5.39	-2.05	-1.90	-1.59	-1.27	0.43
Hybrid Design 2	*Index high-performance*	6.36	6.58	6.78	7.08	7.36	10.99	7.15	5.06	3.23	0.80	4.63	0.58	-1.73	-3.85	-6.56
	Index performance	6.35	6.57	6.78	7.08	7.36	8.28	6.30	5.29	4.52	2.75	1.93	-0.28	-1.49	-2.56	-4.60
	Index non-performance	6.22	6.44	6.66	6.95	7.22	5.99	5.10	4.98	5.19	5.89	-0.23	-1.35	-1.68	-1.76	-1.33
Hybrid Design 3	*Index high-performance*	6.86	7.21	7.50	7.95	8.72	13.33	7.97	5.73	3.65	1.75	6.47	0.76	-1.77	-4.31	-6.98
	Index performance	6.86	7.21	7.50	7.95	8.72	9.85	7.16	5.91	5.17	2.62	3.00	-0.05	-1.59	-2.78	-6.10
	Index non-performance	6.82	7.17	7.47	7.93	8.68	6.60	6.26	5.99	5.96	5.23	-0.23	-0.92	-1.49	-1.96	-3.45

Table 28: CBA results for all three Hybrid products under different index performance scenarios
<u>Source</u>: *AXA Climate*

Hybrid structures, combining Parametric insurance and Reserve, have the following net benefits (with respect to unprotected revenues – see Figure 39):

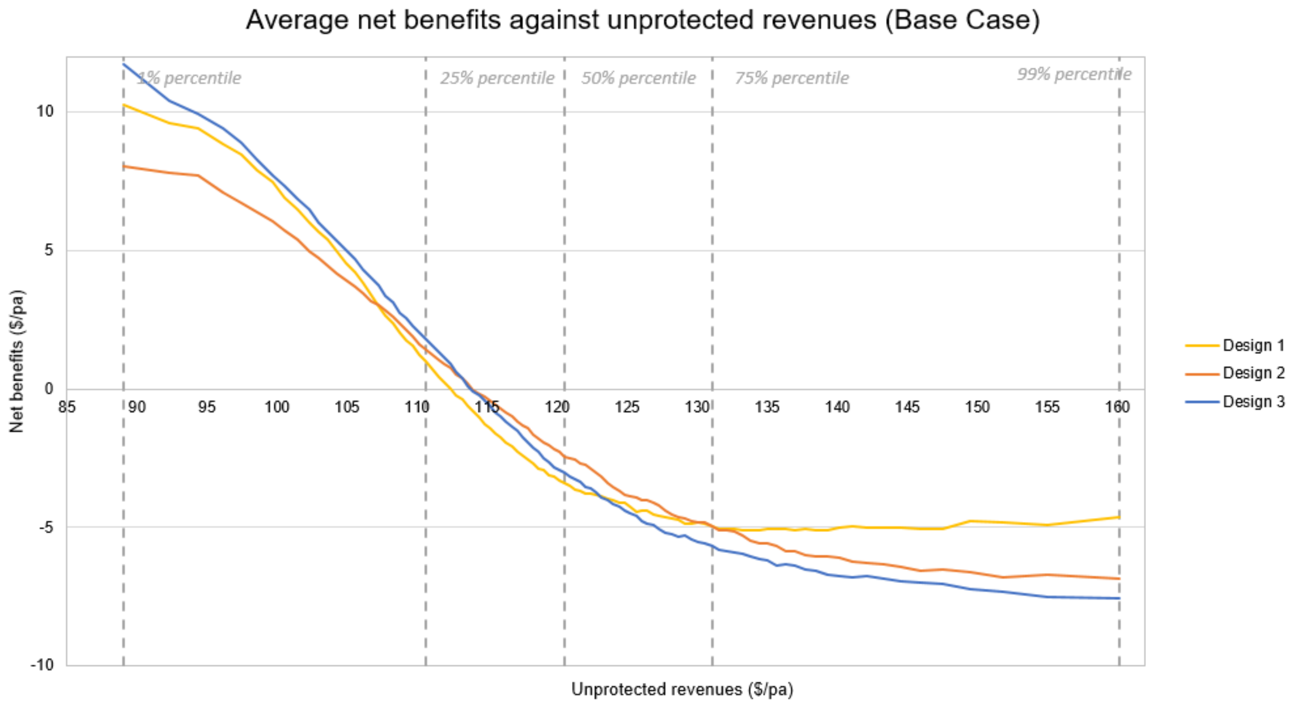


Figure 39: Net Benefits ($/pa) against unprotected revenues ($/pa), hybrid structures one to three
Source: AXA Climate

Parametric Design 3 appears to be at the crossroads of Parametric Design 1 and Parametric Design 2: it offers higher net benefits to farmers for very bad years (low unprotected revenues) thanks to good years (high protected revenues) when premium is paid. It is noticeable that transforming Parametric Design 2 into Parametric Design 3 by decreasing payout granularity from province to territory enables to better protect low revenues. The improvement compared with Parametric Design 1 on these percentiles is explained by the differentiated limit by crop.

* * *

To conclude, sensitivity analysis shows that modelling hypothesis have a high impact on the cover. First, **price elasticity has a strong effect on net benefits**. By reducing the spread of revenues around their average value, elasticity renders limit per crop too high compared to the distribution of revenues. This decreases the benefit of insurance for farmers, as the premium is then used to transform bad years into very good years (revenue wise), whereas turning them into normal years would be sufficient. **Index performance also has a noticeable impact on the efficiency of the cover**: even for a "performance" scenario with 60% correlation between yield and index, the net benefits decrease sharply. Parametric Design 3 seems to be the best cover thanks to the combinaison of soil moisture index, a payout at territory level and of a differentiated limit per crop, which reduces basis risk and allows the cover to be cost-efficient.

CONCLUSION

The purpose of this report was to structure and optimize a cover to protect DRC farmers against drought in the context of an agriculture development program led by an international institution. The optimization was made from the point of view af the farmers, through a cost-benefit analysis, in order to find how to best protect an expected 1,763,668 farmers over five years, two crops (cassava and maize) and 4 provinces, for a total of 26 territories. Two complementary instruments were considered to protect farmers: a Reserve fund and a Parametric Insurance scheme.

The Reserve fund has a capacity of $10 million. The hypothesis is that, of the $20 million available in the general program reserve, no more than half can be allocated to compensate farmers for weather-related events. Two reserve setups were considered and compared:

- Standalone Reserve: a $10 million reserve, not covered by insurance;
- Insured Reserve: a $8 million *insured* reserve, buying a targeted $2 million premium insurance to increase total capacity to $16 million. Our modelling has yet shown that insuring the reserve fund is not cost-efficient.

Results show that insurance the Reserve is, in fact, counterproductive. Indeed, reserve is designed to be used, because any money left at the end of the 5-year period of the scheme will be “wasted” – in a way. This motivates client to calibrate the reserve in order for it to trigger regularly enough and to have a good exhaustion probability, which makes insurance very expensive. It is thus more effective to keep the whole reserve as standalone rather than splitting it to increase capacity.

Parametric Insurance has the largest capacity – no annual aggregate limit for the SMI-based cover, and up to $30 million annual aggregate limit for the SPEI cover for the five years of the program. An international institution pays the insurance premium, for which $20 million have been set aside for the whole scheme duration.

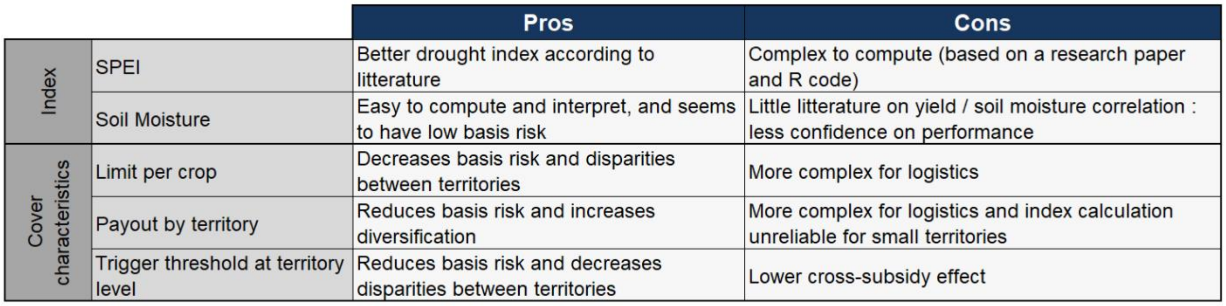
An additional way to improve the cover is to set up a soft trigger to compensate farmers in case of extreme situations not captured by parametric index (such as extreme rainfall or a drought invisible to the index). The soft trigger would be activated by the DRC Government based on information relayed by humanitarian associations on the ground. In order to have a safety net, it is possible to cap the amount that a soft trigger mechanism can unlock for a single occurrence (*e.g.* $300,000) and to allow an increase of the amount in case the drought index strikes simultaneously.

Even for the sole drought peril, the need for a soft trigger is all the more important that the effectiveness of the index itself is highly dependent on its correlation with yield. In other words, for an index-based cover to be efficient, the meteorological index should predict accurately yield drops. In the absence of historical yield data in the DRC, it is yet impossible to estimate this correlation. It is only to create stable results that the CBA has made the unrealistic assumption of a perfect correlation between index and yield for the “Base Case”. In practice, it is more likely that the correlation will be in the range of 40 to 60%, which generates a significant basis risk. Basis risk is particularly strong for the reserve, as the latter is dedicated to covering frequent and less severe events, which are more difficult to capture by the index.

Three indexes have been modelled:

- A **Standard Precipitation Evapotranspiration index** (SPEI, Parametric Design 1), triggering at territory level and with the same payout for maize and cassava ($82 per farmer);
- A **Soil Moisture-based index** (SMI, Parametric Design 2), triggering at *province* level and with a differentiated payout per crop to be closer to the actual value of the loss ($50 for maize and $82 for cassava).
- A **Soil Moisture-based index** (SMI, Parametric Design 3), triggering at *territory* level and with a differentiated payout per crop to be closer to the actual value of the loss ($50 for maize and $82 for cassava).

Based on the Cost-Benefit Analysis, the following chart summarizes Pros & cons of each index and cover characteristics:



		Pros	Cons
Index	SPEI	Better drought index according to litterature	Complex to compute (based on a research paper and R code)
	Soil Moisture	Easy to compute and interpret, and seems to have low basis risk	Little litterature on yield / soil moisture correlation : less confidence on performance
Cover characteristics	Limit per crop	Decreases basis risk and disparities between territories	More complex for logistics
	Payout by territory	Reduces basis risk and increases diversification	More complex for logistics and index calculation unreliable for small territories
	Trigger threshold at territory level	Reduces basis risk and decreases disparities between territories	Lower cross-subsidy effect

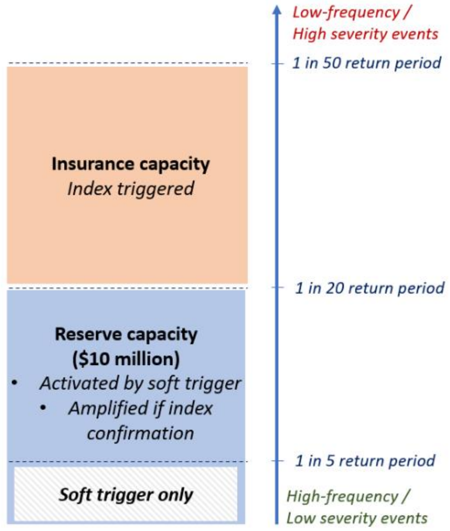
In terms of index, the SMI index (Parametric Design 2) seems more interesting as it is more understandable, easier to calculate for a Calculation Agent and seems to better correlate with yield according to international comparisons. Moreover, correlation pattern is more physical and logical with SMI as it is with SPEI (based on prefeasibility study data)

In terms of cover characteristics, an efficient structure combines a limit per crop, as well as a trigger threshold and a payout by territory. Last section shows that such mix of characteristics enables to create a more interesting cover to protect farmers, based on the CBA. This corresponds to Parametric Design 3.

Combining parametric insurance and a reserve activated by a "soft trigger" is very relevant for farmers. It allows to cover both high frequency / low severity events (with the Reserve) and low frequency / high severity events (with Insurance). However, given the high basis risk of the cover in the absence of historical yield data in the DRC, we recommend to rely widely on soft trigger mechanisms.

We thus suggest the following set-up:

- *For the Reserve*: keep a standalone reserve trigger payout based on a **soft trigger** (with a limited capacity per event), with a **possible capacity increase in case of a simultaneous index strike;**
- *For Parametric insurance*: triggering of payments **by index**. For payouts exceeding a pre-defined amount, we suggest to give the option to the Client to wait for additional information before sending the full amount to the farmers.



The development of the insurance market in the DRC is very recent though. The non-life insurance market was for several decades a monopoly of the Société Nationale d'Assurances (SONAS). This monopoly was removed in 2015 and the first new insurance company licences were granted in March 2019. Current capacity and premium levels are very low: the premium level reached $90.1 million in 2015 (lastest published figures[9]). This is also reflected in the

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[9] AXCO 2021, Non-life Insurance Market Reports, Democratic Republic of Congo, June 2021.

low insurance penetration rate (market premium as a percentage of GDP) in the country for non-life insurance: 0.24% in 2015, a low figure compared to 0.43% in Angola, 1.6% in the Republic of the Congo and 2.56% in South Africa.

Furthermore, agricultural insurance is very limited in the country, and likely to be limited to the protection against fire damage to crops for some of the largest farmers. Parametric insurance appears to be currently non-existent in DRC. There is therefore important work to be done locally, particularly with the government and the national regulator (Autorité de Régulation et de Contrôle des Assurances), but also with key potential insurance partners, to pave the way for implementation of the insurance programme.

Finally, it is important to keep in mind that the cover must be adapted to local context. More information is needed on crop price, elasticity, yield data, as sensitivity analysis shows that cover efficiency drops sharply as soon as one hypothesis changes.

REFERENCES

ALBERGEL C., DE ROSNAY P., BALSAMO G., MUÑOZ-SABATER J., BOUSSETTA S., ISAKSEN L. [2012] « ECMWF soil moisture validation activities », *ECMWF Newsletter – Meteorology*, n°133.

AOUN S. [2018] « Solution dynamique d'assurance paramétrique agricole », ENSAE, Mémoire d’actuariat.

BEGUERÍA S., VICENTE-SERRANO S.M., REIG F., LATORRE B. [2014] « Standardized Precipitation Evapotranspiration Index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring », *International Journal of Climatology*, vol. 34, n°10.

BOUTON V. [2017] « Solutions indicielles de protection du revenu agricole - modélisation et tarification », ISFA, Mémoire d’actuariat.

CÔME T. [2018] « Tarification d’une assurance indicielle pour des producteurs de maïs au Mali », EURIA, Mémoire d’actuariat.

DIVARDJIAN F., NOVAKOVIC M. [2013] « Étude d'une police d'assurance pour les risques de catastrophes naturelles dans les Caraïbes », ENSAE, Mémoire d’actuariat.

FINAS B., GILLES S. [2011] « La gestion indicielle du risque climatique », ENSAE, Mémoire d’actuariat.

HOHL R. [2019] « Agricultural Risk Transfer: From Insurance to Reinsurance to Capital Markets », *Wiley Finance.*

IPPC [2021] « Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change », *Cambridge University Press*.

KAHNEMAN D., TVERSKY A. [1979] « Prospect Theory: An Analysis of Decision under Risk », *Econometrica*, vol. 47, n°2.

KOCH E. [2011] « Étude de faisabilité d'une assurance rendement basée sur indice climatique », Dauphine, Mémoire d’actuariat.

KOULI T. [2018] « Étude relative à la construction et au paramétrage du modèle actuariel nécessaire à la conception et à l'exploitation d'une assurace paramétrique », Dauphine, Mémoire d’actuariat.

MARTEAU D. [2012] « Asymétrie d’information, aléa moral et crise financière ».

PIETTE P. [2015] « Assurance Agricole et Images Satellites : Produit d’Assurance et Arbitrage Financier », ENSAE, Mémoire d’actuariat.

POTOPOVÁ V., TRNKAB M., HAMOUZ P., SOUKUP J., CASTRAVET T. [2020] « Statistical modelling of drought-related yield losses using soil moisture vegetation », *Agricultural Water Management*, vol. 236.

RITLENG F., NGUYEN C. [2014] « Étude d'un produit d'assurance paramétrique contre le risque de pluie torentielle en Jamaïque », ENSAE, Mémoire d’actuariat.

SADOU B. [2017] « Gestion indicielle du risque météorologique - méthodes de tarification pour la gestion d'un portefeuille et couvertures indicielles multirisques », ISFA, Mémoire d’actuariat.

VENDÉ P. [2003] « Les couvertures indicielles en réassurance CAT : prise en compte de la dépendance spatiale dans la tarification », ISUP, Mémoire d’actuariat.

WORLD BANK [2005] « Managing Agricultural Production Risk ».

WORLD BANK [2010] « Cost-Benefit Analysis in World Bank Projects ».

ZRIBI M., ANGUELA T.P., DUCHEMIN B., LILI Z., WAGNER W., HASENAUER S., CHEHBOUNI A. [2010] « Relationship between soil moisture and vegetation in the Kairouan plain region of Tunisia using low spatial resolution satellite data », *Water Ressources Research*, vol. 46.

APPENDIX 1: SOIL MOISTURE LAYER SELECTION

ERA5 provides four layers of soil moisture :

- Layer 1: 0-7cm
- Layer 2: 7-28cm
- Layer 3: 28-100cm
- Layer 4: 100-289cm

We compared data from Czech Republic, where wehave soil moisture index as well as maize yield at territory level, to give insights on the reason behind selecting layer 1. The graph below (Figure 40) shows the correlation between yield and soil moisture index:

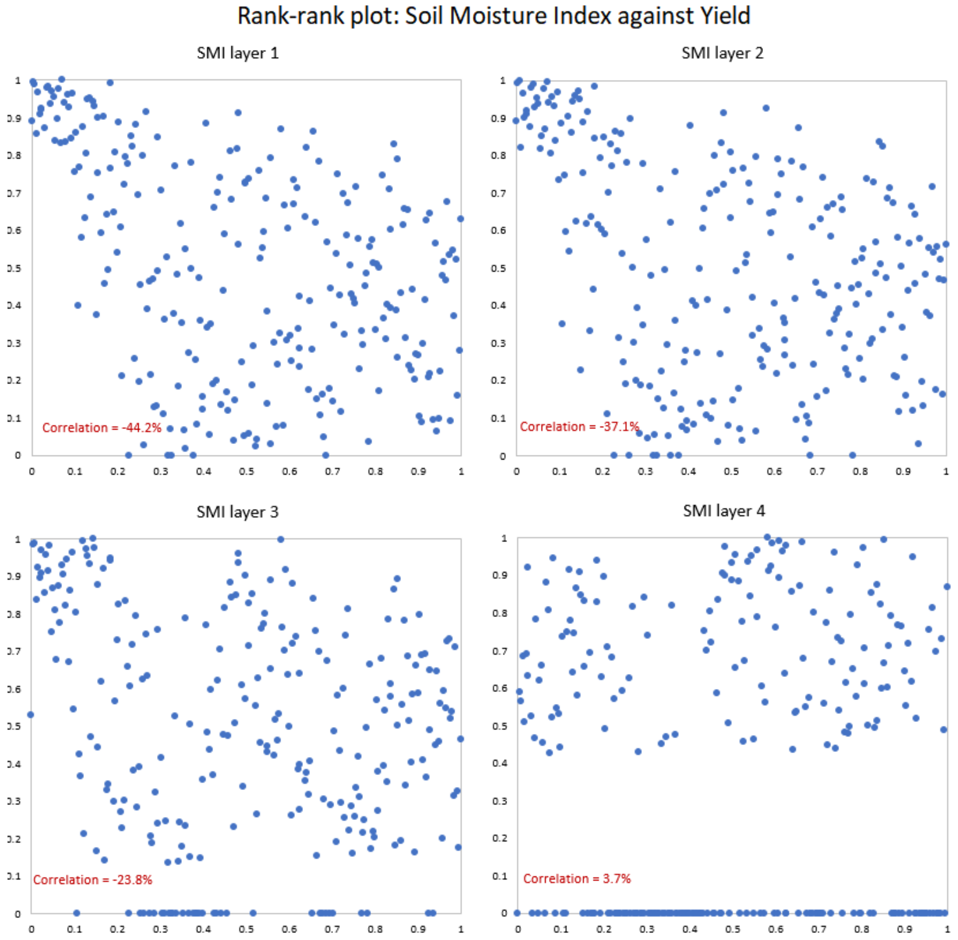

Figure 40: Rank-rank plot of maize yield and soil moisture index, for different layers (Czech Republic)
<u>Source</u>: AXA Climate

Figure 40 shows several interesting results. The first one is that correlation is negative between soil moisture index and yield. This is logical since soil moisture index measures the extent of the drought. Therefore, the higher it is, the worse was the drought, the bigger the drop in yield expected.

Besides from the correlation sign, it is interesting to note that a severe drought (rank close to 1 for the SMI on the *y* axis) gives almost always a bad harvest (rank close to 0 for the yield on the *x* axis). When there is no drought however, the yield still can be bad (for other reasons: diseases, excess of rainfall, for instance). This explains why the points are concentrated around the upper left corner and very spread around the lower right corner.

Figure 40 also shows that last two layers do not seem really interesting in the context, with correlation dropping close to zero. This is quite logical since a hardpan usually forms around 40cm depth, causing most of the roots to concentrate on the first 40cm of the soil. This is why it is more interesting to focus on the first two layers. Even though the first one (0-7cm) shows higher correlation in the present case, it might happen that the second layer (7-28cm) correlates more to yield. Going with one or the other is however not a problem, since there is a very high correlation between the two layers. There is only a smoothing and a time delay when going from layer 1 to layer 2, as we go deeper (time for the rain to penetrate the soil or evaporate a little on the way).

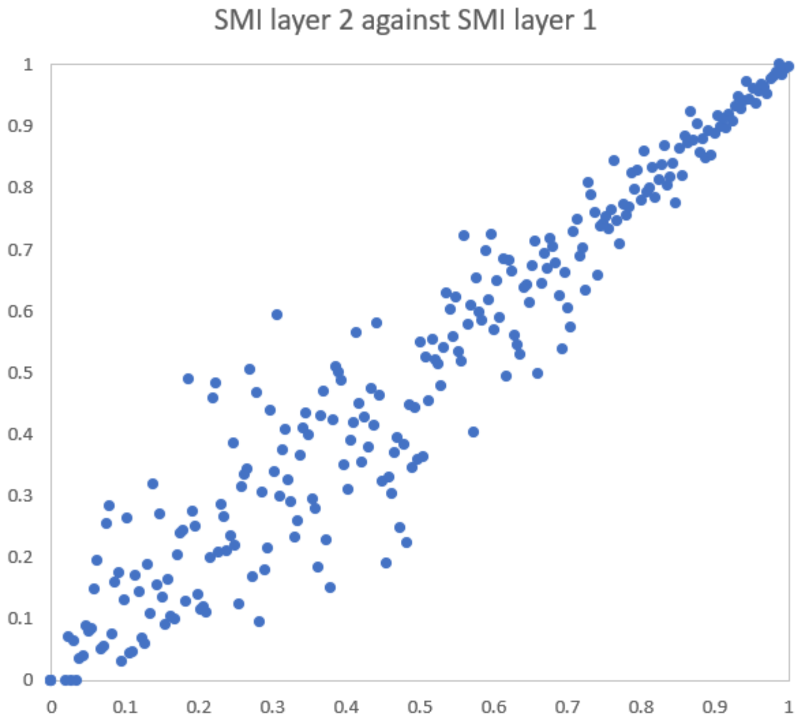

Figure 41: Rank-rank plot between SMI layer 1 and SMI layer 2, Czech Republic
<u>Source</u>: AXA Climate

Figure 41 shows the very strong correlation there is between SMI calculated on layer 1 and SMI calculated on layer 2, especially for extreme drought years (upper right corner). The overall correlation reaches 96%, and seems reasonably high for all percentiles (not only for the worst drought with a percentile close to 1).

APPENDIX 2: LIMIT PER CROP OPTIMIZATION

Figure 42 shows average annual net benefits (expressed in $ per participant) for Parametric Design 2 (based on SMI), in the Base Case scenario, with variation of payout by crop. The payout is expressed in $ per hectar (first table line). There are assumingly three farmers by hectare. Hence, a $300 payment per hectare would make a $100 payout per farmer. A $100 payout per hectare would make a $33 payout per farmer.

The first table below shows that the optimal cover for the farmers at the 1% percentile would be a $50 payout for cassava and a $16.6 payout for maize. This result is yet to be considered with caution as it does not take into account the fact that the farmers don't have to pay the insurance premium themselves.

1% avg	0	50	100	150	200	250	300	*Cassava payout [$/ha]*
0	-	3.21	5.22	5.88	5.78	5.36	4.74	
50	2.52	5.24	6.39	6.50	6.12	5.47	4.82	
100	4.01	5.78	6.44	6.34	5.79	5.09	4.39	
150	4.36	5.70	5.98	5.70	5.09	4.36	3.66	
200	4.30	5.19	5.36	4.97	4.32	3.62	2.89	
250	3.76	4.48	4.58	4.18	3.54	2.81	2.08	
300	3.11	3.72	3.80	3.37	2.71	1.98	1.26	
Maize payout [$/ha]								

25% avg	0	50	100	150	200	250	300	*Cassava payout [$/ha]*
0	-	-0.44	-0.77	-0.86	-0.85	-0.99	-1.39	
50	-0.37	-0.77	-0.95	-0.96	-0.96	-1.24	-1.67	
100	-0.61	-0.92	-0.99	-1.03	-1.18	-1.52	-1.98	
150	-0.82	-1.00	-1.06	-1.18	-1.47	-1.89	-2.41	
200	-0.89	-1.07	-1.25	-1.54	-1.92	-2.36	-2.91	
250	-1.09	-1.31	-1.60	-2.00	-2.41	-2.90	-3.45	
300	-1.40	-1.71	-2.09	-2.52	-2.97	-3.47	-4.05	
Maize payout [$/ha]								

50% avg	0	50	100	150	200	250	300	*Cassava payout [$/ha]*
0	-	-0.69	-1.34	-1.93	-2.38	-2.60	-2.75	
50	-0.70	-1.37	-1.98	-2.52	-2.80	-2.93	-3.16	
100	-1.30	-1.96	-2.51	-2.90	-3.08	-3.29	-3.58	
150	-1.84	-2.42	-2.85	-3.13	-3.33	-3.60	-3.93	
200	-2.25	-2.71	-3.03	-3.30	-3.61	-3.92	-4.29	
250	-2.54	-2.90	-3.26	-3.56	-3.91	-4.29	-4.74	
300	-2.77	-3.17	-3.52	-3.91	-4.31	-4.76	-5.22	
Maize payout [$/ha]								

75% avg	0	50	100	150	200	250	300	*Cassava payout [$/ha]*
0	-	-0.75	-1.47	-2.21	-2.90	-3.51	-3.85	
50	-0.78	-1.52	-2.26	-2.97	-3.61	-4.10	-4.32	
100	-1.54	-2.27	-2.99	-3.68	-4.23	-4.52	-4.67	
150	-2.25	-2.99	-3.67	-4.25	-4.61	-4.84	-5.00	
200	-2.94	-3.61	-4.20	-4.62	-4.90	-5.12	-5.29	
250	-3.45	-4.05	-4.51	-4.85	-5.12	-5.31	-5.60	
300	-3.84	-4.30	-4.71	-4.98	-5.28	-5.56	-5.92	
Maize payout [$/ha]								

99% avg	0	50	100	150	200	250	300	*Cassava payout [$/ha]*
0	-	-0.77	-1.54	-2.29	-3.00	-3.77	-4.53	
50	-0.82	-1.59	-2.35	-3.11	-3.82	-4.59	-5.35	
100	-1.65	-2.41	-3.18	-3.94	-4.65	-5.42	-6.17	
150	-2.46	-3.23	-4.00	-4.76	-5.47	-6.23	-6.91	
200	-3.29	-4.06	-4.83	-5.58	-6.28	-6.95	-7.15	
250	-4.11	-4.88	-5.65	-6.33	-7.02	-7.17	-6.76	
300	-4.87	-5.64	-6.40	-7.02	-7.17	-6.59	-5.28	
Maize payout [$/ha]								

Figure 42: Parametric Design 2 (SMI) net benefits sensitivity to payout by crop
Source: AXA Climate

APPENDIX 3: DEEP DIVE ON KASAÏ NET BENEFITS

It is concerning to note that despite the effort to smooth net benefits between provinces, by introducing a different threshold for each *crop x province* and a different payout value by crop, Kasaï province still has a notably small net benefits at 1% percentile in Parametric Design 2. To explain this unexpected result, the net benefits against the unprotected revenues were calculated, for all years of the scope (see Figure 43 below):

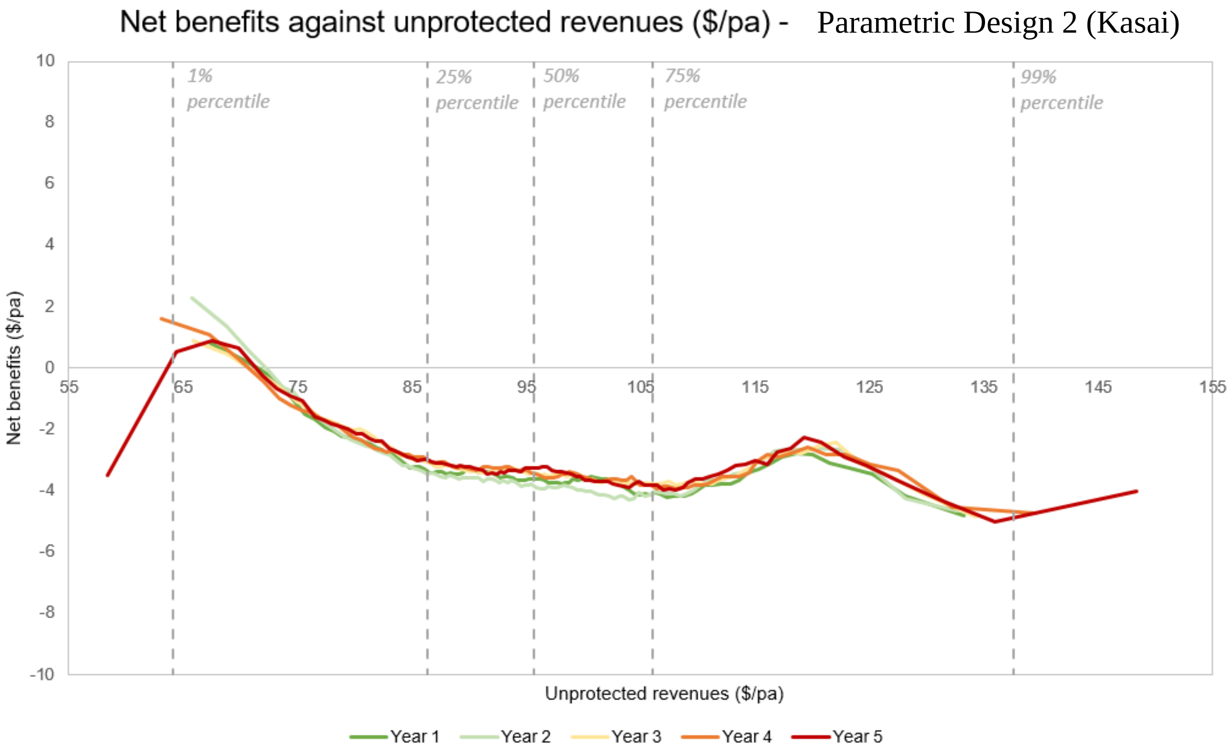

Figure 43: Kasaï net benefits against unprotected revenues ($/pa), Parametric Design 2 (SMI)
Source: AXA Climate

Figure 43 shows that the over-estimated payout for maize has an impact on net benefits. The increase of net benefits observed at around $120/farmer is due to the fact that maize payouts in bad yield situations are so high compared to the price of maize that indemnified farmers find themselves in a situation where they enjoy very high revenues (c.a. 5% highest revenues). It would be more effective for Kasaï province to trigger more often with a smaller payout. Decreasing maize payout from $50 to $30 to obtain a protected revenue around the 50% percentile of revenues ($95/farmer, rather than $120 in the graph below) would decrease premium and increase 1% percentile net benefits, which is what is to be protected, without harming the overall net benefits.