Strategies for applying distributed ledger technologies in index-based crop microinsurance schemes

by

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ABSTRACT

Support for sustainable smallholder farming has long been recognized as a key to healthy and resilient food production. The ideal situation – a global community of geographically dispersed smallholders enmeshed in local economies, thereby reducing waste – is incompatible with the centralizing forces currently dominating development. One need only view the COVID-19 pandemic and associated supply chain breakdowns to see the weakness of an overly connected global food system rife with perverse incentives, namely the centralizing nature of specialization and industrialization.

Crop insurance is a form of proactive disaster risk management used to diffuse risks to agricultural production across space and time with other producers. It is a form of support that countries have long endeavored to implement so that farmers avoid turning to suboptimal traditional risk coping mechanisms. Notwithstanding, traditional insurance programs have been plagued by well-documented challenges creating a severe gap in service offerings, especially among smallholders in the developing world. As climate change raises agricultural risks through heightened uncertainty, it is increasingly necessary to augment the security of smallholder farms through closing the coverage gap.

Fortunately, recent technological advancements have improved the prospect of overcoming barriers to reaching smallholders. Combining the decreasing cost and increasing sophistication of remote sensing and satellite technology with smart contracts and other innovations enabled by distributed ledger technology has the potential address many of the challenges of traditional insurance provision. Blockchain technology affords this potential through providing architecture to reduce transaction costs, increase trust and access, and deepen opportunities for reinsurance. The transparency and immutability of blockchain engenders a unique coordinating capability that allows for benefits superior to other organizing instruments. Despite limitations concerning the current state and maturity of blockchain technology, the pace and direction of development offer promise for near-term composability with key systems and functionality.

This research uses a literature review to trace historical challenges in providing crop insurance and analyzes the opportunity for blockchain to mitigate them. It focuses on evaluating the potential to bolster the provision and uptake of a particular type of crop insurance – index-based microinsurance – through the combination of blockchain technology and public-private partnerships. The aim is to provide an analysis of how blockchain applications can improve existing crop microinsurance schemes and a guideline for how public-private partnerships should be organized to optimize implementation. Furthermore, this research holds in mind the ultimate goal of creating true at cost peer-to-peer index-based crop insurance. That is, after initial investment, coordination, and monitoring by a public-private partnership to overcome startup barriers, it is possible, and optimal, to create new regional smallholder insurance regimes running on decentralized infrastructure.

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Introduction

Along with the reduction of greenhouse gas concentrations, the climate policy agenda in recent years has seen adaption to climate change emerge as an essential part of the response to increasing risks (Hochrainer et al., 2008). Subsequent reports from the International Panel on Climate Change (IPCC) from 2005-2022 have reinforced the urgency for adaptation in both the developed and developing world, as evidenced by the dramatic intensification and forecasts of extreme weather, such as heat waves, droughts, and heavy precipitation (IPCC, 2022). Proactive disaster risk management – the ex-ante developing of strategies, tools, or institutional mechanisms to reduce livelihood vulnerabilities to stochastic shocks – has been increasingly recognized as an important aspect of mitigating adaption risks. Insurance-related instruments have been progressively heralded as crucial disaster risk management tools through their ability to spread and pool risks. Accordingly, broad agreement exists among scholars and leading international institutions on the need for greater implementation of agricultural insurance to augment food security – demonstrated by commitments to disaster risk management (DRM) in Paris Climate Accords and vast amounts of DRM financing with multilateral climate funds alone approving $136M to development projects containing an insurance component between 2008 and 2017 (Weingärtner et al., 2018).

Recent evidence suggests that just a 1% increase in insurance penetration in developing countries reduces the burden of disaster recovery by 22% (Lloyds, 2018). Crop insurance – one form of agricultural insurance – is a risk management tool that can stabilize investment and income for farmers in the case of extreme weather events or natural disasters (Tripoli & Schmidhuber, 2018). Compared to traditional risk-coping strategies, such as rationing or compensation through contingency funds, insurance programs can incentivize risk-mitigating behavior through smoothing income and spreading losses over time. Only 20% of smallholder farms in developing countries, however, have access to crop insurance systems, leaving around 270 million underinsured smallholder farmers. As farms under five hectares of land are responsible for around 50% of global food production, this chronic lack of access to insurance not only threatens the livelihoods of these farmers, but also the entire global food system (Micale & Van Caenegem, 2019). Worst case scenario models indicate that, by 2050, without adaptation measures, agricultural productivity may decline by 17% globally and 50% in Africa (ISF, 2022).

The COVID-19 pandemic and associated supply chain breakdowns highlighted the weakness of an overly connected globalized food system. Increasing specialization due to trade liberalization over the past few decades vastly increased exposure to price risks among smallholders. Corporate enclosure on seed distribution and the centralizing drive of fertilizer use drastically increased production risk. Along with an associated decrease in food diversity and nutrition, this push for a single global market has led to high overall systemic risk across all regions. Much of this drive toward centralization stems from development community dogma surrounding the faulty assumption that economic growth, based on gross domestic product (GDP), equates to human progress. However, recent scholarship around degrowth and circular economies, especially considering exacerbated climate risks, consistently demonstrates the need to radically shift economies back toward decentralized localized production and consumption underpinned by smallholder farms (Hickel, 2019).

Where smallholding producers are decentralized, they must be supported in producing diverse, nutritious food instead of economically squeezed and enclosed. Where producers are centralized there must be transition towards decentralized participation in circular economies. At the same time, smallholder farms also face the challenge of overcoming the incremental cost of insurance while simultaneously undergoing climate-adaptive changes such as shifting from conventional to climate-smart-agriculture (Micale & Van Caenegem 2019). With 58% of rural households depending on subsistence production, there is dually a great need but large difficulty in prioritizing insurance. More attention and institutionalized effort into creating accessible crop insurance for smallholder farmers is thus necessary for building resilience to the impacts of climate change.

This paper focuses on evaluating the opportunity to bolster the provision and uptake of a particular type of crop insurance – index-based microinsurance – through the use of blockchain technology and public-private partnerships. The aim is to provide an analysis of how blockchain applications can improve existing crop microinsurance schemes and a guideline for how public-private partnerships should be organized to optimize successful implementation. Smallholders are specifically targeted due to this from this paper's a priori understanding of three overarching ethics of change necessary promote a resilient food system: localization, diversification, and democratization. Together, these ethics underpin and ethos of decentralization in food production as well as supporting infrastructure like crop insurance schemes.

International financial institutions and bilateral donor organizations are already providing services for insurance programs related to disaster and weather risks that serve smallholding clients across the global south (Hochrainer et al., 2008). Understanding this dynamic, the World Bank created the Global Index Insurance Facility in 2015 to assist with program implementation. Despite these efforts, many of the traditional challenges of delivering sustainable smallholder crop insurance have not been adequately addressed. Key barriers include basis risk, limited awareness and demand from smallholder farms, and costliness due to, inter alia, long claims cycles and poor financial infrastructure. These dynamics lead to a general lack of trust between farmers and insurers, which exacerbate problems of geography and information asymmetry (Tripoli & Schmidhuber, 2018). Furthermore, the oft-informal nature of insurance arrangements in rural areas can exacerbate these issues, as a community's direct or indirect experience with corruption or difficulty receiving payment can drive negative perceptions (Chatterjee & Oza, 2017).

The advent of blockchain technology has created the potential to address many of these issues through decentralized infrastructure. Blockchain systems can securely integrate multiple data sources and direct transfer of wealth to enable standardized digital crop insurance platforms. Linking newly advanced information gathering techniques and tools geared towards index-based insurance with blockchain smart contracts, has the potential to help overcome or eliminate barriers sustainable crop insurance programs, namely reducing transactions costs. While not a panacea, the United Nations, FAO, and a consortium of civil society organizations have created pilot models for integrating blockchain into index-based insurance schemes with promising results (Micale & Van Caenegem 2019).

Method

The format of this study will proceed as follows. First, a literature review on existing literature related to crop insurance is undertaken. The review will cover the evolution of traditional crop insurance research by the international development community with respect smallholder farms. A special focus will be taken on recent index-based insurance models to narrow the field to relevant research. The review will center on historical strategies and models designed to promote sustainable programs as well as recent innovations.

Subsequent to the context provided the literature review, there is a discussion surrounding potential applications of blockchain and distributed ledger technology in index-based crop microinsurance. This section theorizes specific areas and challenges of crop insurance that may be addressed with the incorporation of blockchain. Specific considerations and features of blockchain are described and proposed, along with the presentation of a model currently being tested. With these in mind, an analysis of proposed and currently implemented models is undertaken with respect to the identified challenges and opportunities.

Following the literature review and analysis of potential blockchain applications in index microinsurance, an exploration of potential governance models for public-private partnerships (PPP) will be conducted to develop a framework designed to overcome current barriers to implementation. The focus on PPP governance models stems from the insight that the coordinating ability afforded by blockchain and the nature of index-based microinsurance requires a plethora of actors with different capabilities and financing abilities to create a sustainable mechanism. The framework for these governance models will be developed from an analysis of DRM case studies. Cases from different geographical regions will be assessed to get a holistic view of the applicability of DRM schemes across regions.

Finally, the knowledge generated from the case study exercise will be organized into a general recommendation for the implementation of blockchain-based index microinsurance. Specific considerations will be analyzed and incorporated into the recommended model.

Crop Insurance Literature Review

Agriculturists have always sought mechanisms to reduce the multitude of risks affecting their livelihoods. Over generations, management of weather, biological, price, labor, and other risks has led to a diverse collection of traditional risk-coping strategies. These emergent strategies have become enmeshed within the culture and practice of farming communities. Along with government policy, these livelihood strategies have shaped how farmer's approach risk management (Chatterjee & Oza, 2017).

The following table illustrates some widely used traditional risk-coping strategies. Despite the seemingly informal nature of these strategies, they have been extremely effective in responding to livelihood threats. Notwithstanding, each comes with associated limitations and costs.

Table 1: Traditional Risk-Coping Strategies

Strategy	Risks Addressed	Limitations/Costs
Cultivating a mix of crops	Weather and biological risks	Smallholders cannot get good prices for their output
Staggering crop planting dates	Weather risk	Forgoing optimal output
Nonagricultural activities	Diversification of income	Losing focus on core activity
Follow peers	Overcoming knowledge and information gap	Herd mentality results in lost opportunities
Reciprocal arrangements within the community/mutual help	Protecting cash/income flows	Not effective when covariate risks strike
Aligning with value chain players	Credit and price risk	Risk of being exploited by powerful value chain participants

Source: Chatterjee & Oza (2017)

Not all risks and costs are created equally. Crop rotation and cultivating of a mix of crops is a tried-and-true method of managing weather and biological risks. This type of diversification builds soil health, supporting long-term yields, but requires more time to harvest and reduces the ability to economically procure seeds (Chatterjee & Oza 2017). Generally, this strategy would be optimal for farmer's who are not overly constrained by managing other risks and costs. For example, regenerative methods like crop rotation would be more viable if the farmer were not staggering planting dates, diversifying income with nonagricultural activities, or aligning with value chain players through suboptimal methods like contract farming.

While risk mitigation through using financial mechanisms has existed time immemorial through community collectives and mutual aid, personalized financial tools are understood to be a relatively new and important part of reducing reliance on coping strategies. Literature surrounding the economics of risk-coping strategies began to emerge in the 1980s. Binswanger's (1980) seminal study on risk averting strategies and traditional methods in India demonstrated the extremely expensive nature of risk diffusion and loss management. Notwithstanding high costs, the study found that risk-averse farmers seek various institutional methods to avoid risk. Rosenzweig and Binswanger (1993) later calculated that smallholder farmers in a semi-arid region in India sacrificed 27 percent of expected income in order to reduce risk. Carter (1997) and Morduch (2004) reached similar results regarding willingness to pay to avoid higher order losses.

More recent literature confirms the continuation of costly coping strategies. Jensen and Barrett (2017) show that households often cope by selling off productive capital, rationing, and withdrawing children from school in the face of climate shocks. Robles (2021) compiled numerous studies that highlight that the interplay among the threats of shocks, adverse realized outcomes, and requisite coping strategies is often the bedrock of long-term well-being in rural households in developing countries (Rosenzweig and Binswanger 1993; Morduch 1995; Dercon 2004; Barrett and Carter 2013).

Several studies built upon the foundations of costly risk management, including Ashan Syed (1982), which linked them to the philosophy behind insurance. The study understood it to be possible for farmers to engage in beneficial activities that would otherwise be too risky through shifting risks from individuals to pools. Hazell, Pomareda, and Valdes (1986) conducted a formative study on crop insurance programs across North and South America detailing the types and severity of risks facing farmers. They promoted the importance of government provision of risk-sharing institutions – through subsidies or organized partnerships – to aid farmers due to deep interlinkages with the wider economy, ability to obtain foreign credit, and for the welfare of rural people. The study suggested that crop insurance could lead to greater security through distributing and pooling risk across space and time: losses experienced by farmers in a particular place could be compensated through indemnities paid by reserves of premiums from good years or premiums of farmers in areas less likely to incur the same risks.

From the 1980s onwards, the conceptual importance of insurance as viable risk management tool for farmers became accepted and instituted by governments and development institutions. Writing for the World Bank, Iturrioz (2009) understands the conventional definition of insurance as the transference of the risk of loss from one entity to another, usually in exchange for a premium or guaranteed and quantifiable small loss to avoid a large and perhaps devastating loss. With regard to agriculture, crop insurance is the most common type of type of insurance – representing 90% of the premium market – though agriculture insurance also applies to forestry, livestock, aquaculture and greenhouses (Iturrioz, 2009). The following table displays the most common types of agricultural insurance.

Table 2: Types of Agricultural Insurance

Cover	Description
Crop Insurance	
Multi-peril crop insurance	All risks cover offering comprehensive yield-based indemnity based insurance against all losses other than those specifically excluded.
Named peril insurance	Covers only specified perils like hail, dew, etc.
Index-based insurance	Parametric cover offering payouts based on a historic underlying index like rainfall, area yield, etc.
Livestock insurance	
Cattle insurance	An indemnity-based cover offering payouts in the event of death/disability of insured cattle.
Index-based insurance	Parametric cover based on national census/mortality data of cattle.

Source: Chatterjee & Oza (2017)

Understanding the potential and need for agriculture insurance, governments and private insurers have made concerted efforts to increase availability of programs. Agriculture insurance premiums worldwide nearly tripled, from $8 billion in 2005 to $23.5 billion in 2011, according to a study by reinsurer Swiss Re. Emerging market premiums stood at $5.2 billion in 2011 and have increased their share of total premiums from 13.4% in 2005 to 22% in 2011. However, the key drivers of growth in emerging markets were those with large state apparatuses and administrative capacity: India and China accounted 62% of agriculture insurance premiums in emerging markets (Chatterjee and Oza, 2017)

Many studies have conveyed beneficial results of crop insurance schemes: Mishra's (1994) analysis of the Comprehensive Crop Insurance Scheme (CCIS) of India found that participants were able to reduce high-cost strategies such as selling livestock or equipment and induce investment in perceived – to the risk averse farmer – riskier but better long-term investments. The study demonstrated that smallholder farmers in Gujarat were able to obtain better terms on crop loans through the scheme. Bhende (2005) found that the incomes of farmers engaged in rain-fed farming was positively associated with risk levels and that the availability of formal instrument for reducing risk such as crop insurance enabled farmers to adopt riskier strategies that raised income. Cole, Giné, and Vickery (2017) found that farmers invested and diversified into more rainfall-sensitive cash crops due to the provision of insurance. Cai (2016) used a natural experiment involving Chinese tobacco farmers to show that providing crop insurance increased production by 16 percent.

Despite strong theoretical underpinnings and support in the literature, Morduch (2004) finds that in practice success has been limited and short term. Hazell (1992) argues that traditional indemnity-based insurance has not been effective for farmers in the developing world because of the cost of geographically dispersed farmers, information asymmetries, lack of awareness, and ineffective legal services to ensure contract enforcement, and high transactions costs. These challenges are well-documented, and a number of studies highlight the large degree of moral hazard and adverse, which drive up costs for insurers to unsustainable levels (Morduch, 2006; Miranda and Farrin, 2012; Wu et al., 2019). Given the myriad of issues, Hazell and Varangis (2019) show that governments have really only shown success in large-scale, subsidized multi-peril index insurance. Moreover, using Hazell (1992); Smith and Watts (2010); Fadhliani et al. (2019), Ghosh et al. conclude that scant evidence exists demonstrating that conventional crop insurance has positive effects on farmer welfare.

Index-based insurance was developed to address the limitations of conventional agricultural (usually multi-peril indemnity) insurance. Farmers pay a premium to an insurance provider who then make payouts based on the value of an index rather than on losses measured in the field (Iturrioz, 2009). The indices are based on independent measures – such as temperature or rainfall levels – developed to be highly correlated with production, as measured by yield, revenue, or otherwise. Indices are often created using averages in an outcome related to loss over a certain area, like average crop yield, and estimated with statistical sampling or data based on satellite observations (Ghosh et al., 2020)

The literature suggest that index-based insurance can greatly reduce claims administration costs because the product hinges on objectively determined data and eliminates the need to conduct in-field assessments. Removing in-field observations by insurance providers mitigates the problem of geographical dispersion, long claims cycles, paper-heavy policies, and costly claims disputes – all of which drive up administration costs. For example, instead of having an insurance agent verify crop-loss from extreme rainfall, the existence of weather data would automatically trigger payment without involving the agent in the first place. This system also minimizes the space for moral hazard to operate among actors across the claims verification to payment cycle (Nogales & Cordova, 2019).

Historically, these issues have been central reasons for the lack of insurance uptake by smallholders: premiums are too expensive for risk averse farmers because of the transaction costs associated with administration, moral hazard, and adverse selection. Furthermore, smallholders in rural areas often only have access to informal insurance arrangements with very loose connections to financial infrastructure. This raises the chance that a farmer or community will have difficulty receiving payments or engage with corrupt actors with little recourse. Communities who directly or indirectly experience this gap in trust and service, then, grow negative perceptions on insurance (Chatterjee & Oza, 2017). These dynamics restimulates the lack of demand, driving up costs.

Despite the promise of index-based insurance to address the problems in development literature, several barriers have hindered the growth of these programs. The main disadvantage of index insurance is that because indemnity is no longer linked to a specific damage, providers and producers are subject to what is known as basis risk. Le Fur & Outreville (2020) write that basic risk emerges from the difference between the reality of climatic shocks and actual compensation payment. A certain weather-related event may not trigger a payout for a farmer despite producing massive damage. Alternatively, overcompensation could be provided by the insurer when an index is triggered but there was no actual loss in yield, income, or other measure.

The lack of verifying claims in index insurance thus creates a situation whereby transaction costs are greatly reduced but basis risk increases. In practice, this leads index insurance providers to cover the cost of basis risk by raising premiums. Still, the literature suggest, index insurance premiums and overall operational costs are lower than that of conventional indemnity schemes. Le Fur & Outreville (2020) has examined the possibility of using novel policy calculation methods to reduce basis risk through increasing investments in technology. They conclude that utilizing real options through public-private interaction can help fill the basis risk gap but require improved operation conditions, optimized financial management, and consideration of real climactic conditions (Le Fur & Outreville, 2020).

The study's conclusion relates to another prominent barrier to index insurance identified in the literature: high startup costs. Successful implementation of index insurance requires confidence in the transparency and objectivity of the underlying index. Iturrioz (2009) finds that to achieve degree of objectivity and transparency necessary to a program that is both financially viable for the provider and trustworthy for the producer, there must be sufficiently sophisticated data, a high correlation between the index and producer-level losses, and freedom from influence by either party. Different data systems require different forms of investment; for instance, the establishment of new weather systems, access to accurate satellite data, and relevant financial infrastructure to process payments, execution, and data storage. The costliness and time-consuming nature of coordinating investments and upkeep for this technology have represented a significant barrier for creating index-based insurance (Nogales & Cordova, 2019).

As the purpose of this paper is to explore opportunity to promote insurance uptake by smallholders specifically, the examined literature was narrowed to focus on limitations to index-based microinsurance. In 2018, ISF (2022) identified more than 100 microinsurance active in developing nations, though over 60% of coverage was concentrated in India, Kenya, and

Mexico. They found that the cost of reaching smallholders tended to determine their scaling strategy, requiring substantial subsidies and guiding schemes to be distributed through pre-aggregated farmer networks and bundling services. In addition to basis risk and startup costs for weather information services, Mattern and Ramirez (2017) highlight barriers regarding data. They find that lack of credit histories, historic yield data, and informal contracts pose major difficulties for typical insurance providers to engage with smallholder farms. This reaffirms Morduch (2004), who identified the lack of information to base premiums on as a major practical challenge.

Aside from data, Morduch (2004) also distinguished two other major barriers to microinsurance: the need for reinsurance and need to limit transactions costs. Transactions costs have already been discussed and will be the main focus of the application of blockchain technology. In short, the relatively small size of individual policies has not been sufficient to cover the high transactions costs involved in verifying claims across dispersed rural geographies. While index insurance reduces some of these transaction costs, the next section will discuss the opportunity for blockchain to vastly reduce other important transactions costs, namely in payment, signup, and trust.

Any successful index microinsurance model, however, must also address the problem of reinsurance. Reinsurance is the transference of risk from an insurer to an additional insurer to protect against the risk of the original insurance (Ghosh et al, 2020). Reinsurance is important, especially in an era of growing climate risks, because a large or series of catastrophic events can create an unexpectedly large number of claims at the same time and render insurer insolvent. An insurer not being able to pay claims to participants creates major setbacks in the trust and value that smallholders place on insurance. Thus, having a reinsurer – whether a government, private entity, or NGO – that can prevent the insolvency of the insurer would expand opportunities for index microinsurance (Le Fur & Outreville, 2020).

Reinsurance is especially necessary for microinsurance schemes due to the nature of the typical insurance provider executing the policies. Microinsurance requires an in-depth understanding of the agricultural risks protected by the policy (Itturioz, 2009). Generally, this understanding has been limited to small geographical regions – thus, they often involve very local actors or a combination of a local actor and a regional financial underwriter. As such, microinsurance providers tend to cover homogenous regions full of neighboring smallholders that are subject to similar sets of potentially catastrophic risks (Chatterjee & Oza, 2017). This is what is known as covariate risk; if risk pools not sufficiently diversified to in terms of geography and types of risk, coverage may not be viable because of the lack of available resources (Micale & Van Caenegem, 2019).

This situation creates a strong need for reinsurance for the sustainability of microinsurance schemes. Unfortunately, traditional crop insurance providers have – for aforementioned reasons involving lack of data, small policies, and transactions costs -- typically been unwilling to find partners willing to take on reinsurance risk (Ghosh et al., 2020). Di Marcantonio and Kayitakire (2017) demonstrate that covariate risk and a dearth of economic support by states that barring access to international reinsurance markets is one of the most common constraints of small-scale agriculture insurance.

Recent index-based insurance models, however, allows for greater possibilities for involving reinsurers. Westerhold et al. (2018) found that using discrete indices like rainfall, as opposed to traditional indemnity, increases the ability of the insurer to transfer risk to a reinsurer. An EU Green Paper On Insurance suggests the possibility of using governments as the reinsurers of last resort. States have many more financial tools available to spread losses and risks to climate shocks across different geographies and risk profiles, yet traditionally have only gotten involved via subsidies. Indeed, the paper finds that "state can be of a real financial support under certain reinsurance agreements (e.g. stop-loss or parametric solutions) for that part of capital which is either no longer available or too expensive at less restrictive costs " (EU Finance Consultations, 2013). This would drive up the financial burden for the state but can potentially be funded through mechanisms such as catastrophe bonds to individual households or companies that provide liquidity and awareness of climate risks with egalitarian purpose.

Lastly, this study identifies an important gap in the literature regarding the assumptions crop insurance models generally make about agriculture. Past crop insurance paradigms assume a model of agricultural that is growth-based, industrial and furthering ties to the global market. For instance, literature from Binswanger, Murdoch, Robles, Chatterjee, Iturrioz and others suggest that insurance uptake can help farmers increase "investments" pertaining to industrial equipment, fertilizers, or the purchasing of seeds; Iturrioz cautions that insurance may create the moral hazard of using less fertilizer; Chatterjee finds it risky for farmers to engage in crop rotation because they may not fetch top prices in the global market. Baking these assumptions into insurance models is suboptimal (dangerous, even) because, as scholarship increasingly shows, long term livelihood is supported more by agroecological strategies and local resilience than on purchased inputs like fertilizer or tenuous ties to global prices.

Regardless of the choices individual smallholders make with funds saved from obtaining crop insurance money, crop insurance programs should not assume or promote unsustainable strategies. If any model or paradigm be prescribed or imposed on smallholders, it is recommended to do so through a lens of food sovereignty. Indeed, this study holds that reinforcing the industrial growth-based paradigm may be a reason why so many insurance programs have failed: they further entrench smallholders into positions of greater price and production risk, stimulating the feedback loop of unaffordable premiums and less attractive reinsurance.

In this way, the lack of successful crop insurance programs despite great attention and government subsidies (Morduch 2004, Chatterjee 2017, Fadhliani et al., 2019) can be explained by their tendency to feed smallholders into an inefficient centralized food system. The purchasing of fertilizer and seeds in today's corporatized environment are more and more likely to come from centralized entities such as multinational companies like Monsanto. Reliance on fertilizer and mass-produced seeds breeds further reliance and centralization. Specializing production into certain crops that have higher yields and have connections to global markets incentivizes destructive monoculture (Shiva, 2016). This cycle of centralization raises systemic risks that ultimately results in higher costs of insurance provision.

This study focuses on index microinsurance not only because of the centrality of smallholders to a just and sustainable food system but because the technological advancements of blockchain and climate-sensing equipment pose an opportunity to break this cycle through decentralization and efficient risk-diffusion. This would require innovative systems to shift from relying on yields and incomes for indices – especially as changing climates and damaged soil skew historical data – and toward verifiable ecological data, which would have downstream effects of incentivizing a renewed focus on holistic coping strategies. Furthermore, greater use of ecological data would make use create alignments with the increasing need to monitor changing climates.

Potential role of blockchain in novel index-based microinsurance programs

Blockchain is a distributed ledger technology (DLT) that uses novel cryptographic methods to create and store information in a transparent manner. These near-immutable digital ledgers can securely record all transactions taking place on a given network (GIIF, 2021). The FAO recognizes that DLTs and "smart contracts provide a unique opportunity to bring greater efficiency, transparency and traceability to the exchange of value and information in the agriculture sector." Wherein the collection of information about the state of farms and contracts in agriculture is often incredibly costly, blockchain offers a reliable source of truth (Xiong, et al., 2020).

An exponential increase in mobile connectivity among smallholders has led to greater feasibility of digital approaches to agricultural finance in developing countries. In Tanzania, for example, a 2016 national survey found that 80 percent of smallholders in the country owned a mobile phone and 49 percent had a mobile money account (Anderson et al. 2016). A wider study by GSMA (2016) estimated that out of than 750 million farmers in 69 countries, around 295 million have mobile phones and about 13 million use a mobile money account (Mattern & Ramirez, 2017).

Compared to the high rates of phone ownership, use of digital financial services like mobile money is still relatively small. Notwithstanding, improving services are increasing usage of mobile money. For instance, the well-known digital payment service M-Pesa has more than 30 million users across 10 African countries (Krishnakumar, 2017). Still, mobile money services remain relatively slow and expensive. They are also one dimensional in that they are not easily interoperable with other digital tools, such as identity and wider scale financial management. DLTs can serve as the next iteration of the mobile money, with added prospects for cost-savings, deeper data integration, expanded ownership and access (Celo Foundation, 2021). While communities that currently lack mobile penetration might be excluded from DLT-based insurance programs, this paper understands the process toward providing low-cost insurance provision for smallholders to be an iterative process that would seek to include solutions for those without access to mobile technology.

Against the backdrop, DLTs present major opportunities to address three distinct challenges of index-based microinsurance:

1) Reduction of transactions costs
2) Expanded uptake through increased access and trust
3) Increased risk diffusion and reinsurance opportunities

First, through the disintermediation of transaction processing and data storage, DLTs can utilize digital records and cryptography to vastly reduce transactions costs involved in index-based microinsurance products. This is achieved through smart contracts. Smart contracts are an innovation layered onto the blockchain that can transfer value from one party to another based on a set preconfigured conditions triggered by changes in the data. For instance, the FAO finds that, for weather-indexed crop insurance, geotagging consumer data using mobile phones can be combined with automated weather stations and satellite imaging to remove the need for insurance providers to conduct in-field loss assessments (Tripoli & Schmidhuber, 2018). A smart contract can then auto-execute payment based on this weather data. This system vastly reduces the transactions costs associated with human intervention.

Transactions costs are further reduced through the creation of new, more efficient financial infrastructure. DLTs have ability to transmute value in the form of cryptocurrencies and other backed assets. This allows users – both individuals and organizations – to bypass traditional intermediaries such as banks, increasing cost efficiency. Value transfer using DLTs would also drastically reduce the risks and costs associated cash-based transfers, through entities like Western Union which still account for most financial transactions in the developing world (Mattern & Ramirez, 2017). These technologies are still in their nascent phases and are expected to become extraordinarily efficient.

DLTs have already demonstrated this ability. In 2013, BitPesa launched a DLT-based payment service that enabled African and international businesses to make payments to and from Africa, facilitating a transaction volume of around US$20 million per month (Aglionby 2018). Celo Organization is developing an ecosystem for an open platform supporting mobile-first for inclusive development (Celo Foundation, 2021). By 2016, one estimate showed use of DLT led to global savings of about $16 billion annually on banking and insurance fees (Maity 2016). The Global Innovation Lab for Climate finance estimated in 2019 that using DLT and mobile money platforms combined with automatic verification could reduce costs associated payment 30-60% (Micale & Van Caenegem, 2019). A more recent study by the Lab and decentralized insurance startup Etherisc, estimated that blockchain technology reduces the costs required for policy issuance by up to 41%; premiums for farmers were subsequently reduced by up to 30% (Etherisc, 2020).

Besides reducing transactions costs, the combination of index insurance with DLT can expand uptake through increased access and trust. First, the ability to transfer assets without the use of intermediaries is crucial in that many smallholder farms lack access to the traditional financial system. Often this is due to the lack of state administrative capacity, existence of corruption, lack of a formal banking sector, or geographic isolation. Bypassing these intermediaries and/or the process of transacting in cash helps smallholders navigate access to trustworthy financial infrastructure and, in addition, helps shift perceptions on the value of digital tools (Tripoli & Schmidhuber, 2018).

Even farmers that can access agricultural insurance usually have paper-heavy policies and require substantial manual labor to verify claims, which often induces a lack of trust between smallholders and insurers. This trust gap can be filled by the availability of frictionless and real-time payment services (Tripoli & Schmidhuber, 2018). While DLT index insurance would not solve the trust gap between farmers and the formulation of the policy, in operation, farmers need only trust the weather data used as an index trigger with an intermediary representing farmer insurance for verification. This novel reduction in the length of the claims cycle is seen as a potential key breakthrough in farmer demand for insurance.

Furthermore, while farmers are still not so quick to trust all mobile technology, strengthening the digital finance value chain through DLT could promote access by making signup easier. An example of this enabling environment is the ability to enroll in index insurance through the same platform or provider of loans or credit, which have traditionally been distinct. Similarly, there have been promising pilots of “freemium” signup models where farmers who purchase a bag of seeds are automatically enrolled in an insurance program (Micale & Van Caenegem, 2019). This innovative method was created before the advent of DLT, yet the transparent nature of DLT means that farmers can independently verify their policy on a blockchain instead of needing to trust a centralized server.

The third major opportunity for DLT to help overcome barriers in index-based microinsurance is increased opportunities for risk diffusion and reinsurance. The decentralized architecture of a blockchain or distributed ledger allows any party to independently verify information inputted to the network, such as weather data, policy mechanics, and transactions. This cryptographic innovation has significant ramifications as it allows for interoperability with other actors and data systems. Whereas the lack of interoperability is a major limitation of centralized data structures, DLT can promote integrity and coordination among previously parallel systems (Xiong et al., 2020). For instance, state-run microinsurance providers from different countries using a DLT to store data do not have to rely on one another for accurate information, increasing their ability to work cooperatively.

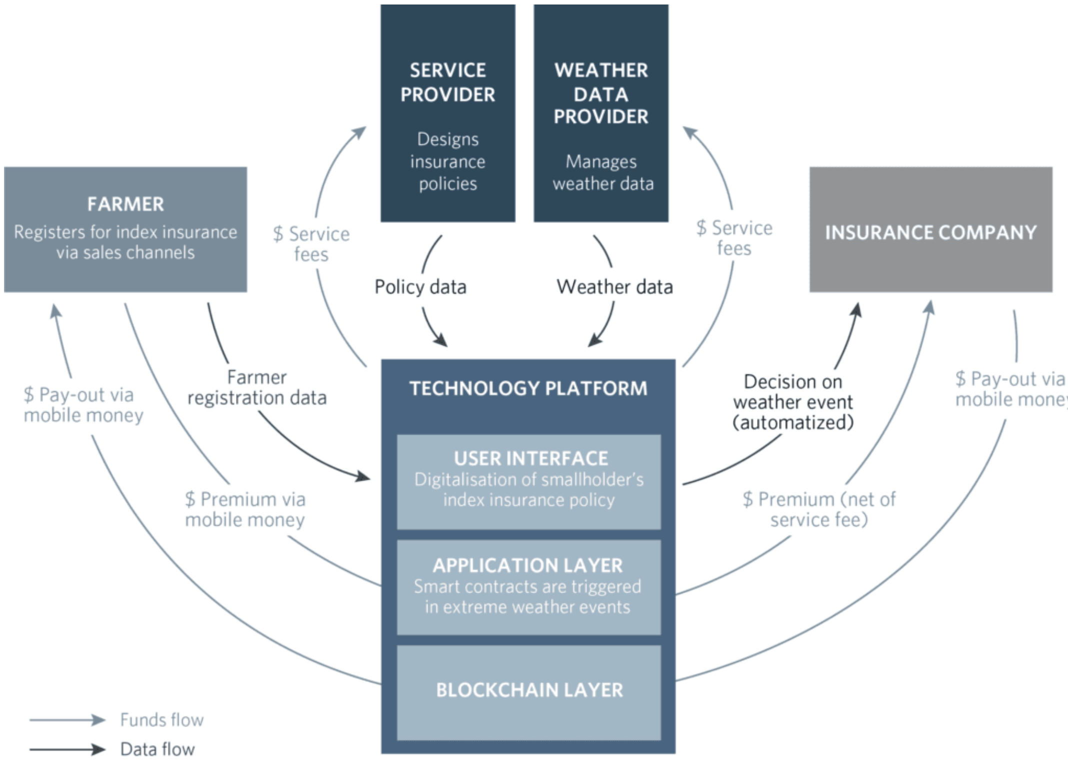
This interoperability among index insurance information structures could vastly reduce risks faced by insurance providers and reinsurance, making their participation more likely. The borderless nature of blockchain allows the flexibility to reflect the reality of farming across geographical regions and in effect more efficiently diffuse risks over space and time. This directly addresses the major problem in microinsurance of programs only tending to cover homogenous regions, which subjects providers and reinsurers to major risks.

With DLT, microinsurance programs can be expanded to cover geographically distinct zones while still being run by local actors. Small policies could be bundled together in decentralized way through DLT to make them attractive enough to be offered by providers and reinsured. They could be distributed at lower cost by intermediaries who currently lack the infrastructure to scale products and effectively track index data across multiple policies (GIIF, 2021). Thus, the coordinating capability afforded by DLT allows it to be a scaling technology that offers great opportunity to drastically reduce the cost of insurance through spreading risk amongst a more diverse and robust set of actors.

Given the promise of DLT to reduce transactions cost, increase trust, and create risk diffusion opportunities, organizations are beginning to implement blockchain-based index insurance programs. WorldCover in Ghana began implementing a blockchain index-based microinsurance program in 2018 by updating its existing infrastructure with DLT. Oxfam, insurer Aon, and local insurer SANASA worked to produce their first on-chain microinsurance payouts in 2019 for paddy farmers in Sri Lanka (Etherisc, 2021). Other projects include UK insurer Skyline working with tea farmers in India and French insurer Atos in Kenya. While the potential of DLT index insurance is understood to be great, current implementation remain at the pilot level (ISF, 2022). This study counts found roughly six programs– all essentially in the planning or pilot phase – that are focused on blockchain-based index microinsurance, with scant data and monitoring publicly available from which to learn.

Notwithstanding the lack of hard data, it is useful to go through the typical model of DLT-based index insurance programs to identify potential benefits, costs, and challenges of implementing these new systems. The diagram below – typical of these theorized or piloting programs -- comes from one of the major initiatives underway, with funding from a plethora of governments and nonprofits, The Global Climate Finance Lab's instrument, The Blockchain Climate Risk Corp. The objective is to pilot and scale up a standardized and digital index platform to strengthen smallholder resilience through access to insurance. The instrument is currently being piloted in Kenya with maize farmers with aim of expanding across Sub-Saharan Africa and into South Asia (Micale & Van Caenegem, 2019).

Figure 1: Blockchain Climate Risk Corp Pilot Model



Source: Micale & Van Caenegem (2019)

DLT-based index insurance instruments typically have three elements: an insurance provider, a user interface, and an application layer. The first element consists of a service and data provider who designs the insurance policy, process payments, and manages customer care and commercialization of the product. The provider collects, verifies, and manages data for the risk model. The second element is a user interface that harmonizes information from the provider (on policies, weather events, etc.) and farmer identification data with payment processing. The application layer is created by a blockchain development organization that builds and maintains smart contract infrastructure on the blockchain where the user interface is built. Thus, elements two and three, with information provided and managed by the insurance provider, is what allows for the interoperability of currently siloed data (Micale & Van Caenegem, 2019).

For the Blockchain Climate Risk Corps, the elements are implemented by different entities. ACRE Africa, a regional insurance provider experienced in index insurance, manages the first element. Sprout Insure and Etherisc, recent fintech startups, respectively operate the second and third elements. Working in conjunction with the Global Innovation Lab, these entities also coordinate with a larger insurance company – UAP Holdings – to manage a larger risk pool, provide reinsurance, and perform payouts via M-Pesa. Here, it is important to note that for the Blockchain Climate Risk Corps, as with other studied DLT-based microinsurance initiatives, that pilot programs are not yet executing payouts using cryptocurrencies. When weather-sensing data inputted into a blockchain triggers execution of a smart-contract payout, an off-chain payout is automatically made from an entity like UAP Holdings through a mobile money service. This is in contrast to the proposed final form of these initiatives where assets exist on-chain and are triggered to exchange wallets via smart contracts (Micale & Van Caenegem, 2019).

The final form of these projects takes shape after gradual scaling up from the pilot phase. Testing and step-wise implementation of these systems is crucial given the complex coordination required to integrate data, payment, distribution and trust. For instance, The Blockchain Climate Risk Crops envisions the pilot taking two to four years. The first year is dedicated to farmer observation with analysis of processes and information systems used by the different elements while other stakeholders engage the private sector to seek funding as well as manage the regulatory landscape. The second (or third) year will see further refining of legal and operational infrastructure along with refining the risk and policy models and improving distribution and reach so as to lower costs. Beyond the pilot, the scaling-up phase involves rolling out a range of products covering multiple crops in different geographies. This requires engaging with a more diverse set of aggregators, insurers, and authorities. Simultaneously, the instrument will transition to its long-term structure of implementing on-chain risk pool and payouts (Micale & Van Caenegem, 2019).

Given the substantial multistakeholder undertaking, the financial needs of this project are high. It is estimated the pilot requires about US$ 620,000 for testing the integrated data system and an additional $200,000 later for integrating payments on blockchain just for the technology and labor (Micale & Van Caenegem, 2019). An additional US$ 10.8 million in premium subsidies is estimated to be necessary in order to provide sufficient demand for the product in pilot phase to test the concept and platform. These subsidies – from both the public and private sector – help decrease premiums for farmers during pilot, encouraging uptake (Chiriac, 2021). Lastly, business development and product development could need as much as US$ 468,000, with an additional US$ 5 million for a duplicate risk pool for testing (Micale & Van Caenegem, 2019).

This ambitious project highlights several important factors in implementing a successful blockchain-based index microinsurance program. First, is the significance of overcoming the startup cost barrier. Given the drastic reduction in operation costs and increased chances of profitability, startup costs vis-à-vis long-term impact are not exceptionally high but are still sufficient large so as to adequately build technology and enhance distribution systems. Second, promoting uptake and implementation also require a consortium of partners on the local level. These partners are critical to onboarding as many farmers as possible in order to hit breakeven points for technological investment. Third, expanded risk pools from expanded services are crucial to lower premiums (Micale & Van Caenegem, 2019). Finally, the necessity of government subsidies as well as funding from non-state sources cannot be understated in getting the initiatives off the ground (Chiriac, 2021).

Given these challenges, costs, and associated learning curves, it is logical to evaluate whether the incorporation of blockchain will be a net benefit to crop insurance systems at all. Recent studies affirm a plethora of specific affordances of blockchain within the realm of insurance, which fall under the scope of 1) increasing coordinating capabilities: through information aggregation, operational visibility, data authenticity, cross-border payments and 2) decreasing transaction costs: through reduced overhead and administration burden, disuse of middlemen, and accessibility (Gatteschi et al., 2018; Tripoli & Schmidhuber, 2018; Micale & Van Caenegem, 2019; Arslanian, 2019; Chod et al, 2019; Xiong et al., 2020, ISF 2022; Cao, 2022). With proper implementation, blockchain systems introduce more transparency, immutability, and decentralization to the existing financial system, thus improving the upon the complex and costly network of third party and hub and spoke systems (Arslanian, 2019).

Furthermore, this paper holds that DLT affords the possibility of true at cost peer-to-peer crop microinsurance. That is, the final desired state of an insurance model where the operation is fully managed by smallholder farmers whose risks are sufficiently diffused by innovative policies coordinated at minimal cost on a public blockchain. Such a system is supported Gatteschi et al. (2018), though it requires deeper maturation of not only DLT but IoT technology and a consortium of public-private actors to cover startup costs.

While there is little debate on the potential affordances of blockchain, the more important question surrounds whether the technology is mature enough to be used in index microinsurance (Gatteschi et al., 2018). Currently, new technologies including DLT and remote-sensing capabilities are not challenging established business models (ISF, 2022). This has less to do with the purported benefits and more to do with the novelty of the technology. For instance, smart contracts rely on countless external services, known as oracles, to take real world data and put them on a distributed ledger. As the insertion of wrong information, through manipulation or otherwise, could trigger payouts or create other major problems in the system, oracles thus have a massive responsibility to be executed and organized correctly (Gatteschi et al., 2018). Oracle systems, along with other immature aspects of DLT – such as the problem of scalability – take time to develop properly and may not be currently ready for expansive use.

This poses limitations to use of DLT in its current form. However, the costs of adopting blockchain are expected to decline as more and more of the technology gets integrated (Arslanian, 2019), and with improvements in oracles and the expanded use of zero-knowledge proofs. Many see blockchain in the immature part of the hype cycle, where it is just beginning to experience the network effects associated with coordinating technology (Gatteschi et al., 2018). Indeed, the potential affordances and global nature of the blockchain ecosystem has helped it grow at an astonishing pace. Moreover, blockchain's use outside of insurance – in the areas of cross-border payments, securing land tenure, and data privacy – ensures future development of integrated technology, ultimately lowering costs and uncertainty that currently pose barriers (Arslanian, 2019).

Another challenge specific to the integration of blockchain concerns negative perceptions surrounding energy use and regulatory environments. Public blockchains have been criticized for the high energy use and associated emissions used by the Proof-of-Work cryptographic method pioneered by Bitcoin. The perception that blockchains are antithetical to sustainable climate action could be a barrier to the accessing of climate funds for grants as well as the participation of governments. Regulatory environments themselves may also be distrustful of blockchain and associated cryptocurrencies. This may make it more difficult for blockchain-based insurance models to be approved by regulatory authorities, especially if systems running in one country are managed by an organization in another (Arslanian, 2019).

Recent developments in the blockchain sphere, however, are mitigating these concerns. Other cryptographic methods on both public and private blockchains have been created and tested that significantly reduce energy use. For instance, the public blockchain Ethereum is transitioning to Proof-of-Stake at the end of 2022, with estimates to reduce energy consumption by 99.7%. Blockchain is also continuing to gain legitimacy in eyes of regulators and other relevant stakeholders. The UN recently published an analysis suggesting wide-ranging applications for the use of blockchain. As sentiment continues to improve and DLTs increasingly display practical use cases, the risk of negative perception and thorny regulatory environments is envisioned to diminish (Bhatti, 2022).

The fact remains, however, that the factors and challenges of implementing a wide-reaching DLT-index insurance program make the endeavor a complex undertaking requiring the sustained long-term cooperation of many stakeholders. The financing, data requirements, distribution channels, interfacing with smallholders, etcetera needs input from not only states but civil society and the private sector. Local insurers that are needed to for tailoring policies to certain geographies and onboarding smallholders have little interest in investing in new products, largely because of lack of technical capacity, increasing risks, and the challenging nature of serving impoverished farmers. Thus, multi-sector collaboration with an active government role is necessary to close the persistent smallholder crop insurance gap (ISF, 2022). This suggests that a public-private partnership (PPP) that incorporates local actors is needed to catalyze a positive feedback loop of cheaper premiums, wider coverage, and greater investment through increased trust and coordination.

Previously mentioned blockchain crop insurance initiatives all involved a form of PPP, yet there has been little to no discussion surrounding the most optimal way to organize participation. Given the downstream effects, this study finds it crucial to develop a framework to inform the design of governance structures for DLT index insurance. Here, it is useful to analyze some recent larger scale multistakeholder efforts – all PPPs – that have sought to fill gaps in disaster risk management (DRM) like index or catastrophe insurance. More clearly, the following analysis focuses on the preliminary design phase of a new transnational insurance schema that draws on insights from case studies with varying organizational structures in the DRM space to create a model geared toward sustainable financing with broad coordination and impact.

Transnational arrangements are the focus due to their ability to garner higher startup financing, the cross-cutting nature of climate risks, and the new opportunity for DLT to operate more smoothly across borders to diffuse risks. Maintaining the end goal of increasing insurance among smallholder farmers but with narrow focus on design process, this following analysis seeks to address only a few of the many challenges inherent to the successful implementation of agricultural insurance. Specifically, what types of actors, roles, responsibilities, and other organizational elements or arrangements best orchestrate institutional coordination around agricultural insurance in order to remedy the main challenge of sustainable financing and asymmetric capacities.

Context-setting for case studies

An insurance PPP is an agreement between the public sector, represented by a national ministry or local authority, and the private sector, represented by the insurance industry and its service providers and distribution partners, that integrates business objectives with public policy goals in an efficient way (Solana, 2015). When applied to agriculture in the context of climate change, these PPPs represent climate finance for "adaptation" rather than "mitigation" because they deal with adapting livelihoods to changing climates rather than aiming to prevent a certain aspect of climate change. This distinction is important as adaptation can produce both public and private benefits. Since the public policy shift toward adaptation is a nascent phenomenon, there is a knowledge gap in how adaptation finance architecture can institutionalize the boundary between public and private responsibility and resulting benefits – essentially, the types of projects the PPP will fund and how funding criteria will create or remake the boundary (Persson, 2011).

Importantly, adaptation to climate change impacts is considered a question of transcending specific local spaces. Vulnerabilities addressed through adaptation are connected by economic, biophysical, and resource flows. It follows that adaptation actions, then, are not confined to the local and local actions may have repercussions elsewhere. A diversity of actors operating across scales and geographies is therefore required for effective adaptation (Chan & Amling, 2019). This suggests that a properly designed globalized or regionalized network of localized insurance requires deliberation on transnational adaptation governance vis-à-vis DRM.

This research takes the definition of transnationalism from Risse as "regular interactions across national boundaries when at least one actor is a non-state agent or does not operate on behalf of a national government or an international organization" (Dzebo, 2015). Though perceived as a crucial piece of pursuing international priorities – as explicitly stated in UN Sustainable Development Goals and the Paris Climate Accord – the role of transnational actors cannot be merely assumed. These actors have varied incentives and take strategic considerations that are not always aligned with international priorities. The voluntariness of transnational action, furthermore, undoubtedly creates unequal patterns of engagement that worsen governance outcomes. Instead of complementing governance, an assemblage of generally uncoordinated actions could induce a fragmented landscape. Malignant fragmentation and unnecessary complexity raise transaction costs among actors and may give rise to conflicts that lead to suboptimal or negative outcomes with regards to opportunity costs (Chan & Amling, 2019).

To reduce reliance on voluntarism, and to optimize for the complementarity and functionality of the coinciding realms of transnational and international governance, scholars have promoted the alignment and coordination of transnational actors by international organizations. 'Orchestration' is an approach increasingly considered suitable for stimulating transnational action on globally agreed-upon priorities in climate governance. Orchestration is a process in which public actors persuade intermediary actors, like transnational regional networks, to align their objectives and targets, and consequently leverage actions by third (target) actors (Chan & Amling, 2019). The subsequent case studies are analyzed with respect to how their different organization elements do or do not contribute to effective orchestration in transnational adaptation governance.

A useful framework for evaluating the orchestration of adaptation governance is Dzebo's (2015) conceptualization of three core issues related to transnationalization:

1. **Scope –** varying initiating actors, organizational forms, and governance structures
2. **Institutionalization –** how projects emerge and maintain activity among stakeholders
3. **Functions –** delineation of governance functions (e.g., agenda setting, capacity building)

The emergent properties of the interplay among these categories are considered more effective if their orchestration is seen to contribute to greater longer term PPP sustainability, primarily evaluated in terms of substantial and sustainable access to financing. Furthermore, as this analysis seeks to support extensive insurance regime covering millions of farmers, the case studies will also be assessed in relation to the OECD's three key aspects of scaling up and replication of climate finance (Kato et al., 2014):

1. Utile design of institutional structures and decision-making framework

Different frameworks exist that allow for checks and balances of implementing programs that have effects on ability to garner substantial finance. Key factors include: the number of steps needed to make decisions and resulting time lags that dissuade the private sector from investment, the manner through which finance is delivered (e.g., direct investment, sub-funds, or technical assistance), and initial access to climate finance.

2. Demonstrating successful interventions at the program or project level

Programs that demonstrate success have more opportunity to receive additional funding and support. Key factors include: ensuring activities are self-sustainable, generating information about the benefits of the program through monitoring and implementation, and communicating that information.

3. National and/or regional policies to enhance enabling environment

Policies that create the basis for a country's ability to access, absorb, and implement climate finance. Key factors include: environments that confidence of the private sector (e.g., stable, coherent policy goals and instruments to achieve them) and the development of state institutional capacities.

The discussion illustrates how certain strategies, mechanisms, and features of the case PPPs support the overall framework for orchestration of transnational adaptation governance. Specific elements will then be incorporated into a recommended model for agricultural insurance.

Case Studies:

Coral Reef Insurance, Quintana Roo, Mexico

In 2018, stakeholders from a variety of public and private sectors launched The Mexican Reef Protection Program (MRPP) to protect and restore Quintana Roo's important natural landscapes. National (The National Parks Commission) and local government, local businesses (mostly tourism), the local science community, international nonprofits (The Nature Conservancy) and businesses (Swiss Re), created the Coastal Zone Management Trust, which provided a new institutional funding mechanism to help operate MRPP (Reguero et al., 2019). MRPP provides a parametric solution that, through international reinsurer Swiss Re, provides a payout to trust fund in the event of predefined extreme weather. The trust fund and MRPP then work in conjunction with local actors to assess needs and deploy funds (Way, 2020).

Though obtaining strong initial funding from local businesses and government, the market mechanism of involving reinsurers helped overcome a financing gap for the initial outlay of the project. The generation of scientific and economic risk assessments through a collaborative effort of local communities, nonprofits, and business was invaluable in bridging access to reinsurer funds. Aligned incentives and the formulation of new entities (trust fund and MRPP) helped the program create extensive multistakeholder collaboration within its governance structure. However, distribution of funds from payouts has been notably slow given the numerous participants (Einhorn et al., 2020). Moreover, participation from a plethora of local groups – and steady engagement with local government who helped create enabling environments – helped to integrate the understanding of risks on ground as well as promote knowledge sharing that led to the creation of a transparent and inclusive system for collecting premiums and using funds (Global Parametrics, 2021).

Innovative schemes likes the MRPP are often created and subsidized by donor agencies or corporate social responsibility initiatives, which may be useful for establishing program infrastructure and operational mechanisms but are not focused on sustainability and scalability beyond the stated duration of the program (Global Parametrics, 2021). However, through engagement of the local financial sector the state government was able to continue the program through the COVID-19 crisis without receiving original subsidies from the government. This required the entrants of new stakeholders that joined the program after it demonstrated success over two years. Entrants included Global Parametrics, a recently created private sector group that helps manage the National Disaster Fund (NDF), a PPP designed to mitigate the challenges in DRM for low-and middle-income countries with contribution from the UK and German governments and global reinsurer Hannover Re (Global Parametrics, 2021). This new participation helped increased local capacities, eventually leading to greater scale.

Index-based weather insurance, India

In 2003, ICICI Lombard General Insurance Company Ltd 29 (ICICI) formed a partnership with BASIX – an institution comprised of a consulting group, two nonprofits, a microcredit agency, and local banks – to pilot the sale of rainfall index insurance to small farmers in Andrha Pradesh, India. The World Bank, through The Commodity Risk Management Group (CRMG), provided technical support. The initiative, which became the first weather insurance project in India and also the first farmer-level weather-indexed insurance offered in low and middle-income countries. Currently, around 12 million farmers now access weather index insurance in India. Replication, though with mixed success, is taking place in countries such as Malawi, Kenya, Mexico, Tanzania, Uganda and Morocco (Kato et al., 2014).

Public support from CRMG and the subsidies from the federal government led helped create the self-sustainability and scaling-up of the program – these strong initial outlays allowed premiums that farmers paid into the program to be relatively small, leading to uptake. This is evidenced by the difficulty in scaling insurance after three years before new government subsidies reinvigorated growth. The OECD also writes that "the weather index insurance by ICICI Lombard and BASIX case would not have been so successfully scaled up, if BASIX had not had thousands of employees in hundreds of local offices in several states in India" (Kato et al., 2014). This led to strong delivery channels and more effective planning for different regions through complementary local partnership and transparent communications with end users.

Importantly, the initiative was able to confer benefits to local level stakeholders. For instance, project evaluators note the dynamic of a "risk discovery function" in which farmers used increased awareness of climate resilient practices to reduce risks, effectively helping to lower premiums. Microfinance institutions also received badly needed support in that the project contributed to lower risk of default by farmers. In turn, international development agencies working in the area were able to optimize project support increase participation by lowering delivery risks and costs. ICICI Lombard and BASIX were able to increase their market penetration as well as enhanced their technical weather data analysis capacities. (Kato et al., 2014).

Adaptation for Smallholders to Climate Change (AdapCC), Latin America and Africa

The AdapCC project began in 2007 to support coffee and tea producers in Latin America and Africa in employing strategies to adapt to the risks and impacts of climate change. AdapCC's structure was a PPP organized between Cafédirect,a British beverage company, and the German Technical Cooperation (GTZ) on behalf of Germany's Federal Ministry for Economic Cooperation and Development (BMZ). Cafédirect facilitated access to their network of producers and assisted in communication activities – including pre-project interviews with farmers – while GTZ planned and implemented the project (Christiansen et al., 2012).

The pilot PPP, which included multifocal adaption projects on both mitigation and adaptation, was financed by grants from GTZ (48%) and technical assistance from Cafédirect (52%). Another source of finance was the sale of voluntary carbon credits obtained with technical assistance from Cafédirect. Building partnerships between various public and private actors was an underlying principle of the project. Indeed, partnerships among local institutions, farmers, and international actors was seen as useful in agreement on adaptation solutions. Involvement of local public institutions helped create a sort of positive feedback loop to incorporate these strategies into wider local politics and development (Kato et al., 2014). For instance, the Kenyan Ministry of Agriculture – not an initial participant – began to cooperate with AdapCC in 2010 to introduce new adaptive agriculture practices (Christiansen et al., 2012).

Both the public and private organizations involved had an eye towards scaling, with a focus on the concept called 'multiplying institutions;' exploring how the institutional structure could produce partner networks among relevant actors to scale up and replicate initiatives at various levels. Not only did this principle of 'multiplying institutions' help scale Cafédirect's network, but this ability to scale increased access to financing through making the initiative more attractive to large international donors (Kato et al., 2014). These multiplying institutions strengthened the capacity of relevant public institutions as well as adopted local political and organizational forms – such as cooperatives in Chiapas, Mexico – helping to spur smoother implementation. Finally, this mixed investment model – private, public, and in-country support – was bolstered by the fact that Cafédirect was not strictly motivated by financial return but reinvested profits toward further improving resilience to climate risks (Christiansen et al., 2012).

Regional sovereign risk pools – CCRIF, PCRAFI, and ARC Group

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) is a risk pooling instrument owned and operated by Caribbean governments. CCRIF began in 2007 and was the first regional fund providing parametric insurance for governments in the case of extreme weather events. Initial funding from the Japanese Government helped develop the facility, which then capitalized from contributions – totaling $70M – through a multi-donor Trust Fund including the governments of France, Canada, the UK, Ireland, Bermuda, the EU, the World Bank, as well as the Caribbean Development Bank and membership fees from participating governments (CARICOM, 2022). This extensive funding helped establish the initial startup and implementation of CCRIF by reimbursing the new entity's operating costs, such as claims and reinsurance premiums, for the first five years. When CCRIF expanded in Central America, additional donor funds helped to reimburse operating costs to participating governments for another four years. Donor support helped to cover payouts and reinsure premiums, allowing CCRIF's to retain member country premiums and participation fees, as well as more quickly build up its capital (InsuResilience, 2019).

Early substantial capital also helped CCRIF to develop two key implementation strategies. First, the facility built the capacity to prepare individualized risk profiles for each member country and modifies the accounted for risk in its respective underlying products. Thus, CCRIF is able to tailor toward individual country needs – also helping the institution continually improve models – while still maintaining a large, capitalized risk pool. Second, CCRIF launched a technical assistance program in 2009 geared toward regional knowledge building, professional development, and local disaster risk reduction support. This program helps to increase uptake and the entire local DRM ecosystem (Martinez-Diaz et al., 2019).

Despite its sizeable funding, CCRIF operates independent of these donors as a segregated portfolio company. It created segregated underwriting pools, portfolios, and differentiated capital for different business lines that operates under management by a council of finance ministers from participating countries. Most participating governments pay premiums out of national budgets without assistance prior to reimbursement. CCRIF's constant engagement with donors helps to provide funding boosts through sustained dialogue to multilateral organizations such as development banks and global climate funds. Furthermore, CCRIF relies on coordination with outside public actors – such as the U.S. National Hurricane Center – for portions of operations and data management. The facility also benefits from engagement with InsuResilience – a global consortium of V20 and G20 countries, civil society, international organizations, the private sector, and academia organized at the 2017 UN Climate Conference for DRM finance and insurance solutions to climate resilience – in strategic planning , knowledge management, and coordination (InsuResilience, 2019).

The Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) is an institutional mechanism created in 2016 for the scaling up of regional collaboration on resilient climate finance by Pacific Island Countries (PICs) based on the perceived success of CCRIF. At the conclusion of the PCRAFI pilot insurance program in 2015, Pacific Island countries and development partners launched a standalone facility to continue the insurance program. That facility consists of two legal entities, PCRIC and PCRIF. PCRIC is an insurance company owned by PCRIF and domiciled in the Cook Islands. PCRIF is a foundation governed by a council consisting of donors and members from PCRIC countries. Initial funding – more than $40M in grants – was mobilized by InsuResilience to create the PCRAFI Multi-Donor Trust Fund (MDTF) with the UK, the US, Japan, and Germany as contributors. Funds were provided in a phased manner with additional contributions made upon further engagement. Participating governments benefitted from premium support through subsidies and concessional financing provided by the Japanese Government over the first two years (Martinez-Diaz et al., 2019).

Like CCRIF, the facility is implemented in collaboration with regional development agencies and transnational partnerships such as the Disaster Risk Financing and Insurance Program – a partnership between the World Bank and the Global Facility for Disaster Reduction and Recovery. Staunch data sharing and multistakeholder collaboration in all areas, including technical insurance and legal support has contributed to success. PCRAFI also focuses on a technical assistance program to strengthen institutional capacity and access to disaster risk finance. This multifaceted capacity building program includes three levels of engagement: market-based instruments, public financial management, and knowledge management and learning. Importantly, this capacity building entity is not operated standalone, rather by other relevant stakeholders; namely, the World Bank and two regional groups – The Pacific Island Forum Secretariat and The Pacific Community (PCRAFI Program, 2018).

African Risk Capacity (ARC) is a Specialized Agency of the African Union to build institutional capacity among governments to respond to increased climate risks through collaboration and innovative financing. Founded in 2014, ARC Group is comprised of ARC Agency and ARC Limited, a hybrid mutual insurer and commercial arm that underwrites risk transfer products and offers parametric insurance (GIIF, 2021). Stemming from the similar impetus and recognition of CCRIF's success, ARC was formed by the African Union member countries, World Food Programme (WFP) experts, and other development partners to create an

African-owned regional insurance risk pool. ARC Agency is governed through a Conference of Parties that have signed the ARC Establishment Agreement – 35 have signed and 13 countries regularly purchase insurance – while ARC Limited is independently run. ARC Limited was initially capitalized with a $98M 20-year noninterest-bearing loan from German and British development agencies. To repay this loan, ARC Limited places small surcharges atop country premiums. ARC Agency is fully funded from donor resources, often utilizing recurring grants (Martinez-Diaz et al., 2019).

While CCRIF and PCRAFI create tailored risk profiles for participating countries, ARC invests considerably more resources and attention on an individualized approach, requiring an extensive preparatory process before being able to purchase insurance. This includes not only modeling country-specific risk hazards (like CCRIF and PCRAFI), but also the development of contingency plans to guide government use of ARC payouts. Contingency plans must delineate the use of insurance payouts within existing country systems and how they will reach and protect the most poor and vulnerable people in the country (Martinez-Diaz et al., 2019). ARC also has a more extensive capacity building program than CCRIF and PCRAFI, spending far resources – 50 employees and a $15M budget in 2019 – on country engagement.

Though ARC has been able to provide around 30 million Africans with access to insurance, uptake has been limited by premium affordability. This challenge is exacerbated by the traditional reliance on premium payment with entirely national resources, as opposed to other regional risk pools that receive concessional finance through donors or development banks. This situation can be partially traced to an explicit decision during the initial design of ARC to not offer direct premium subsidies. Following COP26, however, donor engagement and increased international agreement on the benefits of adaption finance led to the establishment of a funding pot dedicated to directly subsidizing ARC premiums (GIIF, 2021). In addition, the recently developed ARC Replica program has expanded liquidity in risk pools by creating the ability for humanitarian organizations to purchase an ARC insurance policy that mirrors the sovereign coverage obtained by the country where the organizations operates (Martinez-Diaz et al., 2019).

Southeast Europe and Caucasus Regional Catastrophe Risk Insurance Facility (SEC-CRIF)

SEC-CRIF was an initiative developed by the UN International Strategy for Disaster Reduction (UNISDR) and the World Bank with collaboration from Regional Cooperation Council of South East Europe to create coordinated action to promote insurance instruments with regional coherency. SEC-CRIF is distinct from CCRIF and related regional risk pools in that the project stemmed from a layered multilevel stakeholder collaboration in the South Eastern Europe Disaster Risk Mitigation and Adaptation Programme (SEEDRMAP), created to reduce the region's risk to disasters. Due to this structure of existing within a broader portfolio of risk reduction, SEC-CRIF was mainly managed by representatives from participating countries ministries of finance (UNISDR, 2010).

SEC-CRIF was funded by donations and grants from The Swiss Government, the Global Environment Facility (GEF - a multilateral climate fund), The European Commission, UNISDR, as well as by loans from the World Bank. The regional approach and integration with

SEEDRMAP helped to garner support from international organizations to continually increase contributions to the managing trust fund. Investments in data management and other substantial upfront costs – barriers to the emergence of private insurers – were covered by the GEF as these multiuse investments were seen as saving future costs. Similar to PCRAFI, participating countries collaborated to form a nonprofit catastrophe reinsurance company, Europa Re, to facilitate private demand for insurance and to develop and implement policies (Zakout, 2012)

Discussion of different elements

Analysis of the seven case studies revealed specific elements that contributed to effective orchestration in the mobilization of large-scale financing for transnational adaptation governance. Each element is discussed with examples from cases with regard to how they fit into the orchestration framework and engage with core issues of transnationalization:

Demand-Led Local Ownership

PPPs that conferred ownership to more localized actors tended to be able to mobilize larger amounts of funding. For instance, institutional mechanisms for the Quintana Roo PPP were not only fully owned by local government, businesses, and CSOs but also instigated by actors who understood the need for coverage. In the ICICI Lombard case, the institutionalization of BASIX helped the PPP work closely with local organizations such that farmers understood costs and benefits of the program (Pauw et al., 2016). Promoting awareness, financial incentives, and voluntary schemes were common strategies that bolstered end user demand.

There is also a high degree of interplay among other factors, as projects whose intended beneficiaries owned more of the management and implementation tended to express more other positive factors. For instance, the institutionalization and scope of ARC Group – with African Union controlling the specialized agency, donors contributing mainly just funding, and extensive engagement prior to purchasing insurance – helped to increase uptake among Africans generally skeptical of insurance and international aid (Martinez-Diaz et al., 2019).

Engaging the Private Sector at Complementing Layers

Every PPP engages the private sector in some capacity, however, strategically incorporating organizations motivated by profit should look different for different projects. All projects suggested that delineating specific governance functions for the private sector at the outset leads to a more utile design and decision-making framework. For instance, a few projects relegated use of these non-state actors to the role of information exchange and procurement. Moreover, the creation of a new private sector entity under multistakeholder management was a common theme that helped to coordinate entities while avoid major governance pitfalls.

Overall, the private sector requires a strong enabling environment prior to engagement. This requires increased predictability, specificity, and transparency among other stakeholders in the PPP. More clearly, increasing the financial attractiveness for involved actors can bolster confidence and help overcome initial barriers for private sector actors. In the SEC-CRIF case, the strengthening of regulatory conditions by SEEDRMAP was able to create more buy-in from the local private sector (UNISDR, 2010). The sector also supported the project due to its creation of new publicly available weather data. ICICI India sparked more interest in weather-based insurance leading to bolstered private sector capacities to contribute to the positive feedback loop. Generally, financially sustainable projects require identifying and analyzing the market barriers and risks surrounding multistakeholder adaption activities (Pauw et al., 2016).

Regional Approach

This analysis finds that a regional approach is more likely to garner the resources and engagement necessary to large-scale orchestration than an individual country or global approach. Reports from the SEC-CRIF case indicate that a regional approach helped to diversify risks, reduce premium costs, promote information exchange, and led to more funding from international donors (UNISDR, 2010). Moreover, regarding insurance specifically, nationwide schemes are usually not suitable for least-developed countries as they generally lack insurance infrastructure, require high premiums, and have competing priorities. Thus, a regional approach – such as ARC – would broaden these countries to participate in disaster risk insurance. Global approaches, on the other hand, suffer from incorporating vastly different risk profiles and forecasting models, as well as complications from bureaucracy.

Despite their advantages, regional approaches still face major barriers to obtaining substantial and sustainable financing. The PCRAFI, CCRIF, and ARC cases all demonstrated how unaffordability and unmet payout expectations led to a sizable reduction in insurance uptake by countries, ultimately decreasing the financial attractiveness for all stakeholders – raising premiums for other countries in the initiative and increasing financial uncertainty for private sector actors. Gaps in insurance product offerings were also seen to lead to the same set of problems (Hirsch, 2021).

Notwithstanding, The World Resources Institute (WRI) suggests multiple strategies to address the current shortcomings of regional DRM pools, such as organizing targeted premium support – supporting vulnerable countries to obtain or in keeping insurance – or incorporating secondary triggers that provide recourse and resources when parametric policies do not trigger (Martinez-Diaz et al., 2019). Moreover, PPPs with streamlined and transparent mechanisms for monitoring implementation, as in the GTZ case and those with access to greater monitoring technology, were likely to reduce risks and costs, leading to greater orchestration and financial attractiveness (InsuResilience, 2019).

Scale-up and Replication

Unsurprising given the capitalist globalist paradigm, the potential to scale demonstrated to be an important factor toward encouraging large-scale sustainable finance and credible commitment from donors. Regarding scope, PPPs that utilized individual organizations with capacity to operate in multiple jurisdictions tended to be able to replicate programs to reach more people. Institutionalization with as many stakeholders as possible seemed to produce PPPs that were likely scale. Those PPPs with the functions of large multilateral orgs and governments relegated narrowly to monitoring and financial orchestration – with implementation left to a consortium of the private sector and CSOs – tended to be able to scale-up and replicate through demonstrating success by scaling up at a reasonable pace.

Similarly, PPPs that began with smaller pilot projects with more organic growth of actors and strategies showed more successful scaling through enacting relatively more utile designs and enabling environments. For instance, analysts note that "transitioning the PCRAFI pilot program to a regionally owned, independent entity was an important step to scale up and institutionalize the regional risk pool" (Martinez-Diaz et al., 2019). This suggests the wider point that piecemeal approaches that demonstrate success in the context of enabling environments and strategic institutionalization are more likely to secure concessional funding from donors.

Limiting costs of insurance to lower-income countries and households

The interrelatedness of these elements cannot be understated, and this last factor is no different: PPPs that minimized the cost to the end user were more likely to exhibit other elements normally present in initiatives with sustainable financing. For instance, subsidies by the government of India were crucial to scaling of the ICICI Lombard project (Kato et al., 2014). Conversely, a lack of previous concessional finance for ARC countries exacerbated the challenge of affordable premiums (Martinez-Diaz et al., 2019). Of course, it is also difficult to parse causality in this factor as projects already exhibiting sustainable financing usually have the capacity to limit costs downstream, helping them to scale and/or create demand among beneficiaries, creating a positive feedback loop.

However, case analyses indicate it sufficient to state that pro-poor mandates are an important but not necessary factor in orchestrating sustainable financing. Interviews from the ARC case – the only regional approach with specific pro-poor elements incorporated into its design – showed a direct causal link from its pro-poor focus to the ability to obtain massive amounts of concessional financing. Moreover, while CCRIF and PCRAFI were relatively effective at securing initial financing, the lack of pro-poor design elements made it difficult to determine the extent to which poor and vulnerable people were aided by the project – thus making it harder to demonstrate success. Broadening the collective understanding of pro-poor mandates from the household to country level during the design process – scoping, institutionalizing, and functionalizing a PPP– then, should lead to greater ability to garner a variety of sources of long-term concessional financing (Martinez-Diaz et al., 2019).

Recommendation

Bringing the discussion of the most effective design of a blockchain-based agriculture insurance initiative back to the fore, the dynamics of these various elements of PPPs lend support to a design that includes a regional approach and an explicit pro-poor mandate that is owned and implemented locally with implementation support from the private sector and monitoring and finance from state-run entities. Such a design would, as much as possible, institutionalize tools like secondary triggers, targeted premium support, and individualized (localized) modeling with extensive capacity building processes. Overcoming market barriers with support from multistakeholder coalitions to incentivize private sector action leads to greater economies of scale and cost reduction downstream. This seems to be best accomplished through concessional finance and a focus on effectively distributing the governance function of capacity building; some contexts may call for more participation from state-related entities while others would simply need public entities to fill implementation gaps of local actors, CSOs, and the private sector.

This recommendation holds that PPP design characteristics are best utilized and organized for scale when incorporating a newly created entities for financial management of funds and the risk pool, such as MRPP (Quintana Roo) or ARC Group/PCRAFI, as well as multi-stakeholder alliances akin to InsuResilience. These bodies should be organized to capture concessional financing and should seek political participation from actors with budgetary responsibilities. Moreover, this analysis promotes the Climate Vulnerable Forum's idea of a new climate risk financing instrument that uses a layered approach to accessing different tranches of contingent multilateral debt based on beneficiary risk and ability to pay (Martinez-Diaz et al., 2019). Succinctly, this calls for greater commitment, coordination, and significant mobilization of investment – on mostly concessional terms –from advanced economies and large transnational climate actors that enables flexibility for different regional approaches and climate vulnerable countries.

Conclusion

This study finds this recommendation to be a useful framework for orchestrating the design of a novel blockchain-based index insurance program. The coordinating capabilities offered by distributed ledger technologies combined with regional governance mechanisms have strong potential to overcome traditional barriers to index insurance through access to sustainable finance: on-chain data makes systems more transparent, accessible, and less costly. Investments in DLT-based index PPPs could allow for the investments to contribute to a positive feedback loop of efficiency, trust, uptake, trust, and expanded services. This implies that the more integrated data systems become with regard to climate and digitization of the agricultural value chain, the more cost savings and thus access can be created. These mechanisms have the potential to minimize the cost of risk-mitigating crop insurance and support adaption by smallholders to climate change.

Glossary

***Blockchain* –** A ledger of accounts and corresponding transactions that are written and stored by all participants through a consensus mechanism

Distributed Ledger Technology (DLT) – Any technology, including blockchain, that writes and stores transaction information using a consensus mechanism and without a central authority

Indemnity – The determined economic loss due to actual agricultural loss

Index-based insurance – Insurance whereby indemnity is calculated as an index using a pre-determined measure of yield, income, or other that is based on a trigger. It is a specific type of parametric insruance.

***Microinsurance* –** A form of insurance provided to individual entities and smallholders that entail very small premiums and payouts

***Orchestration* –** a process in which public actors persuade intermediary actors, like transnational regional networks, to align their objectives and targets, and consequently leverage actions by third actors

***Oracle* –** A piece of software the takes external information from the real world and codes it such that it can be used in a blockchain or other distributed ledger technology

***Parametric Insurance* –** A type of insurance where payouts are based on a certain trigger, like wind or rainfall

***Insurance Premium* –** The payment made by the insured in order to receive coverage

***Public-Private Partnership (PPP)* –** Any combination of entities representing the public sector, private sector, and civil society

***Reinsurance* –** A risk diffusion method whereby the insurance provider receives insurance from a third party to protect against overwhelming simultaneously occurring risks

***Risk Diffusion* –** The spreading of risks among different nodes in a system

***Risk coping strategy* –** Activities undertaken under abnormal circumstances to deal with a shock

***Smart contract* –** A contract that can be coded into software and automatically executed by the input of data as a trigger

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