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HANDLING THE WEATHER INSURANCE, SAVINGS, AND CREDIT IN WEST AFRICA

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ABSTRACT

Farmers in developing countries face a wide array of risks. Yet they often lack formal financial instruments to protect against risks. This paper examines the impact on consumption, investment, and welfare of the separate provision of three financial products: weather insurance, savings, and credit. The paper develops a dynamic stochastic model to capture the essential features of the lives of West African rural households. The model is calibrated with data from farmers in Burkina Faso and Senegal, to assess quantitatively the effects of three policy interventions. For each intervention the analysis first considers a benchmark scenario that abstracts from the flaws that affect each instrument; later the assumptions are relaxed. Weather insurance offers the largest welfare gains at each level of wealth, although the gains are significantly reduced by introducing a multiple on the insurance premium. Over time, however, savings can lead to substantial gains, higher than those achievable by unsubsidized weather insurance.

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Handling the weather: insurance, savings, and credit in West Africa

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1 Introduction

Agricultural income is subject to many risks ranging from weather uncertainty, to pests and diseases. The intensity of these risks is exacerbated in developing countries where on-farm work constitutes the main source of income. In the absence of functioning financial markets, households need to rely on a host of informal strategies, since they cannot shield their consumption from agricultural income shocks through formal financial products. For example, they may run down assets or borrow in bad years. When they choose this road, they may rely on moneylenders who charge high interest rates, or on friends and relatives who however may dispose of insufficient funds. These informal strategies have indeed limited effectiveness even against idiosyncratic shocks (e.g. [Townsend \(1994\)](#), [Fafchamps and Lund \(2003\)](#), [Gertler and Gruber \(2002\)](#)). Farmers are in even direr conditions when facing covariant shocks that affect all households nearby and therefore essentially eliminate the networks' ability of sharing risks.

Uninsured income risk affects consumption also indirectly, by discouraging innovation and risk taking. Rare but severe weather shocks may induce farmers to under-invest in high-return, but also high-volatility projects, as shown by theoretical ([Fafchamps and Kurosaki \(2002\)](#)) as well as empirical ([Morduch \(1990\)](#), [Dercon \(1996\)](#), [Dercon and Christiaensen \(2011\)](#), [Hill \(2009\)](#)) work. Reducing investment in projects with higher but more volatile returns has welfare consequences. For example, [Walker and Ryan \(1990\)](#) found that in semiarid areas of India, households sacrifice up to 25% of their average incomes to reduce exposures to shocks.

These high welfare cost due to uninsured production risk suggests that farmers could largely benefit from the provision of the right financial instruments.¹ In this paper, we examine three formal financial products and assess their impact on investment, consumption, and the consequent welfare implications for rural households in West Africa. Specifically, we study stylized contracts for weather index-insurance, savings and credit accounts, based on the formal financial instruments available for the rural households living in the study area. Each of these products has the potential to improve farmers' welfare, yet none of them completely abstract from complications that may limit the extent of the gains achievable.

Weather index insurance contracts provide new insurance possibilities precluded by traditional indemnity insurance contracts. Under index insurance contracts, the payout is based on an independently observable and verifiable index (such as weather at a local weather station) rather than an on-field assessment of farmer losses. Index insurances overcomes asymmetrical information problems affecting indemnity insurance, and is therefore potentially appealing also to smallholders ([Skees, Hazell and Miranda \(1999\)](#)).² Index insurance is not however immune from drawbacks, notably basis risk which arises because of the imperfect correlation between the insurance payout and farmers losses ([Clarke \(2011\)](#), [de Nicola \(Forthcoming\)](#)).³ Along with basis risk, also high

¹We examine the effectiveness of selected financial products and acknowledge that other instruments, such as improved irrigation, could be used to mitigate the negative consequences of weather shocks.

²Adverse selection, moral hazard and costly loss assessment have led developing countries to abandon programs supporting indemnity insurance due to the prohibitively expensive costs for smallholder farmers.

³Differences in soil composition or exposure, or in the slope of the plots can indeed change the impact of rainfalls

insurance premium, liquidity constraints, lack of trust and poor understanding of the product have been identified as determinants of the low take-up of index insurance observed empirically (For instance, see [Cole et al. \(2013\)](#), [Giné and Yang \(2009\)](#), [Hill, Hoddinott and Kumar \(2011\)](#), [Hill and Viceisza \(2012\)](#)).

Savings may also allow an individual to better insure against risk, by allowing an individual to create a buffer in good years and draw it down in bad times to cover uninsured losses. Indemnity-insurance and savings act as substitutes under certain conditions ([Dionne and Eeckhoudt \(1984\)](#)). Index-insurance and savings, however, play different roles. Savings can be used to insure farmers against covariant as well as idiosyncratic shocks, while index-insurance offers protection only against the former. However, this benefit may be a very expensive form of insurance against large shocks and an ineffective means of insuring against shocks that occur in quick succession ([Deaton and Paxson \(1994\)](#)).

In developing countries, lending to agricultural investments is typically limited by banks' inability to manage the excessive volatility of their loan portfolio as farmers' income is mainly derived from uninsured on-farm work. Banks inflates the cost of borrowing by the probability of default in order to limit their exposure to agricultural shocks. Excusable state-contingent default is therefore priced into the cost of the loan contract ([Udry \(1994\)](#), [Giné and Yang \(2009\)](#)). As a result, farmers are reluctant to borrow and cover the cost of "risky" agricultural inputs, such as fertilizer. Offering a loan with excusable state-contingent default may thus be a means by which access to agricultural finance is increased for smallholder farmers. However, these schemes also have their challenges. Banks are also subject to basis risk and will have to engage in discussions with farmers to explain under which circumstances debt is forgiven. Banks may be concerned that conditional debt forgiveness will undermine a repayment culture. Although farmers will increase their access to credit and insure lending as a result of this scheme they will not be able to insure their livelihoods. Offering index insurance to banks, rather than farmers, may provide a suitable way to extend lending to agricultural investment by curbing banks exposure to production shocks ([Miranda and Gonzalez-Vega \(2011\)](#)). For example, weather index insurance policy will be sold to rural microfinance institutions in Peru to help offset loan defaults and liquidity problems caused by El Niño-induced excess rainfall ([Skees and Collier \(2010\)](#)).⁴

We set-up a dynamic stochastic optimization problem of consumption and investment and perform counterfactual analysis in order to assess the impact of three formal financial risk-management instruments. A key feature of the model is that on-farm investment is subject to multiple sources of risk, both idiosyncratic and covariant in nature, and that a large part of this uncertainty is covariant. This allows us to correctly model the basis risk inherent in some of the financial innovations available. We numerically solve the optimization problem using calibrated parameters based

on yields, thus preventing the insurer from accurately predicting the losses suffered by households. Similar issues arise for farmers who live farther away and experience different rainfall patterns than those measured by the weather stations. In order to minimize this issue, index insurance can typically be sold only within a limited radius (30-50km) from the weather stations used by the insurer.

⁴We model and analyze credit contracts that permit and prohibit the possibility for farmers to default.

on crop model as well as existing evidence in the literature focusing on Burkinabé and Senegalese farmers. We then show the impact on consumption, investment and welfare from the separate provision of three financial instruments: weather insurance, savings and credit. We start our analysis considering the effects from the provision of the “optimal” contracts (from the farmers’ point of view) and then relax these assumptions and investigate the impact from providing more “realistic” contracts.

We recognize the advantages and disadvantages of our empirical strategy. It allows directly comparing the strengths and weaknesses of each financial instrument using a common framework of analysis. We can therefore easily assess the relative welfare implication for the development of the market of each financial product. The caveat is that the results of the simulations depend on the specification of the model. To ensure our results are as realistic as possible we rely on the existing evidence from the literature to guide our theoretical design and empirical calibration.

Our results would therefore complement the existing evidence on the behavioral impact of these financial instruments. In recent years, a number of randomized control trials have started to provide information on the effect on consumption and investment from increased access to insurance ([Karlan et al. \(2011\)](#), [Cole, Giné and Vickery \(2011\)](#)), savings ([Dupas and Robinson \(2013\)](#)) and insured credit ([Giné and Yang \(2009\)](#)). On one hand, these studies provide clean estimates on the behavioral consequences of one financial product at the time. On the other hand, we provide a comprehensive analysis of all the instruments within a single framework and complement the behavioral impact with welfare analysis.

2 Model

2.1 Baseline scenario

We construct a dynamic model of farmers in developing countries facing aggregate weather risks and idiosyncratic shocks, in order to characterize their consumption and investment decisions and the welfare levels they consequently can achieve. Under the baseline scenario, financial markets are absent and households can rely only on themselves in order to shield consumption against income fluctuations.

In each period farmers decide how much of their resources to consume, $c_{i,t}$, how much to keep in liquid assets, $a_{i,t}$, and how much to invest in agricultural inputs, $k_{i,t}$ from which they earn farm income. In the following period, they realize their level of wealth, $w_{i,t+1}$, which depend on two separate components: the stochastic farm income and the deterministic value of liquid assets. Examples of these riskless and return-free assets would be grains kept in store, or cash kept under the mattress assuming minimal crop losses and inflation rates respectively.

Farmers earn farm income according to a Cobb-Douglas production function with decreasing marginal returns. Farm production depends on two factors (agricultural inputs, $k_{i,t}$ and labor $l_{i,t}$), and it is subject to two kinds of shocks (a covariant shock capturing weather vagaries, η_{t+1} , and an idiosyncratic shock representing health shocks, $\epsilon_{i,t+1}$). Farmers make their optimal investment

decisions before knowing the realization of either shock.

Income in period $t + 1$, $w_{i,t+1}$ is given by $w_{i,t+1} = \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha l_{i,t}^{1-\alpha} \eta_{t+1} + a_{i,t}$, where \mathcal{A}_i is an individual-specific time-invariant productivity coefficient that is log-normally distributed with mean 1 and variance $\sigma_{\mathcal{A}}^2$. The distribution of the weather shock, η_{t+1} , and the idiosyncratic shock, $\epsilon_{i,t+1}$, is empirically calibrated from the data as discussed in Section 3.

Each household maximizes the expected present discounted value of consumption $\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j u(c_{i,t+j})$ where $u(c_{i,t}) = \frac{c_{i,t}^{1-\rho}}{1-\rho}$ is a constant relative risk-aversion (CRRA) utility function with a coefficient of relative risk aversion ρ . The optimization problem can thus be written as:

$$\begin{aligned} V(w_{i,t}) &= \max_{k_{i,t}, a_{i,t} \geq 0} [u(c_{i,t}) + \beta \mathbb{E}_t V(w_{i,t+1})] \\ w_{i,t} &= c_{i,t} + a_{i,t} + k_{i,t} \\ w_{i,t+1} &= \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha l_{i,t}^{1-\alpha} \eta_{t+1} + a_{i,t} \end{aligned} \quad (1)$$

The first-order conditions are computed by equating the marginal utility of consumption today to the expected discounted marginal utility of consumption tomorrow:

$$\begin{aligned} u'(c_{i,t}) &= \beta \mathbb{E}_t [u'(c_{i,t+1}) \alpha \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^{\alpha-1} \eta_{t+1}] \\ u'(c_{i,t}) &= \beta \mathbb{E}_t [u'(c_{i,t+1})] \end{aligned} \quad (2)$$

Solving for Equations 2 allows us to derive the finite target level of wealth towards which the household will converge. It equals the level of wealth in the t^{th} period that corresponds to the expected amount in the following period $t^{th} + 1$, and plays an important role in the analysis, since the calculation of the welfare gains from the different policy interventions are based on it.

The scope of the paper is to investigate the impact of the provision of index insurance, savings, and credit on consumption, investment and welfare for farmers. We thus incorporate these financial instruments in our theoretical framework. For clarity, we introduce one element at the time.

2.2 A market for weather insurance

First, we assume that a well-functioning market for weather insurance is established. This market for weather insurance allows households to insure against the covariant shock η_{t+1} affecting their income from agricultural production. However, as discussed in Section 1, it is unlikely that the weather insurance product will insure households perfectly against η_{t+1} , because of these design limitations, not all of the covariant shock will be covered.

Two recent papers have furthered our understanding of the nature of demand for index insurance ([Clarke \(2011\)](#) and [de Nicola \(Forthcoming\)](#)). Each paper models basis risk differently, but importantly they both treat it as quite different from the additive background risk that is present in traditional models of demand for indemnity insurance in which the uninsured losses are entirely independent of the insured event. In this paper, all non-insured shocks to agricultural production -even health shocks to the labor a household can allocate to crop production- are multiplicative

and as such if farmers can purchase only weather insurance, even if it insure perfectly against the covariant source of risk, they would not fully insure.

This framework allows us to consider both the design issues associated with the contract and the fact that, however well designed, a contract designed to insure covariant sources of yield risk will not insure farmers against idiosyncratic shocks such as health shocks that constrain the supply of labor to agricultural production in a given season. The take-up and welfare impact of insurance is limited by such design imperfections, but also by these other uninsured sources of non-covariant risk.

We denote the insurance design effect as ξ_{t+1} and assume that it is log-normally distributed with mean one and standard deviation, σ_ξ . The idiosyncratic source of risk, $\epsilon_{i,t+1}$, is left entirely uninsured by this insurance product, and this will be another source of basis risk to the household that ultimately would like to insure all the risk to their crop production income.

A household can buy multiple units of weather insurance. The actuarially fair price of each unit is given as $\mathcal{P}_t = \int_0^1 (1 - \eta) f(\eta) d\eta$ since η is distributed between zero and one. Insurance may not be sold at an actuarially fair price, but at some multiple, $\theta \geq 1$, above its actuarially fair price, in order to cover the costs of marketing the product, and of transferring some risk to international markets.

We assume that households decide whether or not to purchase insurance in period t prior to the realization of shocks in period $t + 1$. However, we assume that household's pay for the insurance in period $t + 1$, implicitly granting zero-interest loan to farmers to pay the insurance premium, and allowing farm income in period $t + 1$ to be used to pay for the insurance. Although this is not typically how index insurance has been marketed in developing countries, this approach reflects how agricultural insurance is sold in a more mature market like the US ([Liu and Myers \(2012\)](#)).

The decision problem for the household thus becomes:

$$\begin{aligned} V(w_{i,t}) &= \max_{k_{i,t}, a_{i,t}, \iota_{i,t} \geq 0} [u(c_{i,t}) + \beta \mathbb{E}_t V(w_{i,t+1})] \\ w_{i,t} &= c_{i,t} + a_{i,t} + k_{i,t} \\ w_{i,t+1} &= \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^{\alpha} l_{i,t}^{1-\alpha} \eta_{t+1} + a_{i,t} + \iota_{i,t} ((1 - \eta_{t+1}) \xi_{t+1} - \mathcal{P}_t (1 + \theta)) \end{aligned} \tag{3}$$

where $\iota_{i,t}$ are the number of units of weather insurance the household decides to purchase.

If θ and σ_ξ are zero, and farmers can observe the realization of their idiosyncratic productivity before deciding how much insurance to purchase (i.e. if the insurance contract is actuarially fair priced and abstracts from any source of basis risks) farmers are fully insured and optimally set $\iota_{i,t} = \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha$. However, it is no longer optimal to be fully insured as soon as one of these three conditions fails to hold, and numerical solutions need to be found in order to determine the optimal amount of weather insurance that a farmer will purchase, $\iota_{i,t}$.

2.3 Better savings instruments

Second, we introduce the possibility for households to invest in risk-less and interest-earning assets to save income in one period and transfer it to future periods. These assets help households to better smooth income shocks from one period to another, however, they may not protect effectively against large shocks, as anticipated in Section 1. As the work by Dupas and Robinson (2013) shows even though many households may have access to savings accounts that offer a positive rate of return, they may need encouragement to save. We could also think of this intervention as being one that encourages households to save in the interest-earning assets that they may already have access to (such as through labeling, earmarking or social commitments).

We modify the model to account for improved savings instruments, by introducing a positive return, \mathcal{R}^a , on resources held as riskless assets, $a_{i,t}$:

$$\begin{aligned} V(w_{i,t}) &= \max_{k_{i,t}, a_{i,t} \geq 0} [u(c_{i,t}) + \beta \mathbb{E}_t V(w_{i,t+1})] \\ w_{i,t} &= c_{i,t} + k_{i,t} + a_{i,t} \\ w_{i,t+1} &= \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha l_{i,t}^{1-\alpha} \eta_{t+1} + \mathcal{R}^a a_{i,t} \end{aligned} \quad (4)$$

When deciding the optimal allocation of capital, farmers will balance two contrasting effects. On the one hand, given the assumption of decreasing returns to scale in the production technology, the marginal productivity of capital of agricultural production is inversely proportional to the amount of resources invested, thus at low levels of capital farmers may invest more in agricultural production and less in the safe asset that yields a lower return. On the other hand, farmers want to invest in the safer asset that guarantees a constant return in order to protect their future consumption from the higher income volatility that would derive from investing all their resources in more productive but riskier technology.

2.4 Lending for agricultural investment

Finally, we consider the effects of providing access to formal credit for financing capital investments in production. In order to assess the impact of extending credit to farmers we consider two separate scenarios. We initially assume that farmers do not enjoy limited-liability credit contracts, so that their optimization problem corresponds to:

$$\begin{aligned} V(w_{i,t}) &= \max_{k_{i,t}, a_{i,t}, d_{i,t} \geq 0} [u(c_{i,t}) + \beta \mathbb{E}_t V(w_{i,t+1})] \\ w_{i,t} &= c_{i,t} + k_{i,t} + a_{i,t} - d_{i,t} \\ w_{i,t+1} &= \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha l_{i,t}^{1-\alpha} \eta_{t+1} + a_{i,t} - \mathcal{R}^d d_{i,t} \end{aligned} \quad (5)$$

where $d_{i,t}$ is the amount of loan taken out at the interest rate \mathcal{R}^d . Given that $\mathcal{R}^d > 1$, farmer would take out a loan, i.e. $d_{i,t} > 0$, only if they do not hold any liquid asset, $a_{i,t} = 0$.

We realize that this is a rather restrictive credit contract and that in reality banks may offer

limited liability contracts. The possibility of default on their debt is indeed one of the reasons why banks are reluctant to lend for agricultural investments. These activities carry large risks and consequently expose to sizeable risks banks' lending portfolios. When farmers enjoy limited liability contracts, the bank is able to insure their loan portfolio against production shocks experienced by farmers. This default risk is priced into the loan offered by the bank through the interest rate, and is insured by the bank purchasing insurance for the portfolio of agricultural lending products it offers. In particular, we assume that the bank can insure against the same covariant index insurance as the farmer, but at a lower unit price given the larger scale of contract it purchases. The bank however observes the actual realization of the covariant shock only with a certain probability, μ , so that with probability $1 - \mu$ farmers still have to pay back their loan even if they are hit by the worst shock. Once limited liability contracts are offered, farmers' optimization problem thus becomes:

$$w_{i,t+1} = \begin{cases} \mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha \eta_{t+1} + a_{i,t} - \hat{\mathcal{R}}^d d_{i,t}, & \text{if } \eta_{t+1} > \tilde{\eta}_{t+1}; \\ \mu(\mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha \eta_{t+1} + a_{i,t}) + (1 - \mu)(\mathcal{A}_i \epsilon_{i,t+1} k_{i,t}^\alpha \eta_{t+1} + a_{i,t} - \hat{\mathcal{R}}^d d_{i,t}), & \text{otherwise.} \end{cases}$$

where $\tilde{\eta}_{t+1}$ is the extreme weather event that triggers default. The interest rate they pay, $\hat{\mathcal{R}}^d$ reflects the higher cost of lending for the bank due to default, that is the interest rate \mathcal{R}^d paid by farmers in the absence of limited liability is inflated by the cost of the insurance premium against the shocks that would trigger default.

3 Calibration

In this session, we discuss the calibration of each of the model parameters used to numerically solve the model and based on data from Senegal and Burkina Faso.

The expected power (CRRA) utility function farmers maximize is characterized by two parameters: the discount factor β and the coefficient of relative risk aversion ρ . The discount factor is assumed to be the same in Senegal and Burkina Faso and set equal to 0.9.⁵ The level of β corresponds to the inverse of the rate of return on riskless assets (\mathcal{R}^a). The intuition behind this comes from the fact that, in the absence of risk, farmers equate the cost of delaying consumption to the benefit of increasing investment.

Risk preferences are typically estimated using laboratory or field experiments or survey questions. While these data are unfortunately not available for Burkinabé farmers, we can exploit accurate information for Senegalese farmers and assume the same coefficient of relative risk aversion also for Burkinabé households. Specifically we rely on [Charness and Viceisza \(2012\)](#) that compare three distinct estimation strategies in order to elicit risk preferences and understand which method yields more reliable estimates.⁶ Using these replies, through back of the envelope calculations we

⁵In the literature, the values of the discount factor β range between 0.76 and 0.99. For example, [Zimmerman and Carter \(2003\)](#) fix the discount factor at 0.95 when studying the saving and portfolio decisions made by farmers under risk and subsistence constraints.

⁶[Charness and Viceisza \(2012\)](#) elicit risk preferences through: (1) lotteries à la [Holt and Laury \(2002\)](#); (2) investment decisions framed according to [Gneezy and Potters \(1997\)](#); (3) non-incentivized willingness-to-risk responses. [Charness](#)

derive that the CRRA coefficient corresponds to 1.39, suggesting that farmers are mildly risk averse. Estimates of the CRRA coefficient for African households vary widely in the literature. This is well captured by the different conclusions reached by two recent experimental studies: [Harrison, Humphrey and Verschoor \(2010\)](#) estimate a CRRA of 0.5 while [Yesuf and Bluffstone \(2009\)](#) find a CRRA of 4.2. We rely on [Charness and Viceisza \(2012\)](#) for two reasons. First, their work is fielded in one of the countries in our study, while both [Harrison, Humphrey and Verschoor \(2010\)](#) and [Yesuf and Bluffstone \(2009\)](#) are based on Ethiopian households. Second [Charness and Viceisza \(2012\)](#) analysis compare and select the most reliable estimates, thus minimizing possible measurement error.

The production function is assumed to be a Cobb Douglas where labor and capital are the production factors. Since leisure is not included as an argument in the utility function, we assume that farmers entirely allocate their labor endowment to on-farm production. The value of the capital share, α , is set to 0.35 in Burkina Faso and 0.32 in Senegal based on the estimates of the Solow model done by [Durlauf, Kourtellos and Minkin \(2001\)](#) for these countries.

We recognize the important role played by the production shocks and calibrate the aggregate weather shocks, η_t , and the idiosyncratic shock, $\epsilon_{i,t}$ combining evidence from the data and literature. We rely on the crop water satisfaction analysis (CWSA) module to derive the empirical distribution of the weather shock. The CWSA module estimates the impact of rainfall variations on farmers' yields that combined with the rainfall probability distribution approximate the frequency and size of η .⁷ The covariant shock takes value between zero and one where zero corresponds to the most disruptive weather shock. The crop model captures shocks due to both excess and lack of rainfall, thus in case of either a devastating drought or flood would be equal to zero. In Figure 1 we plot the empirical distributions of the aggregate shock, η , and shows that farmers in Senegal are exposed to larger variations but farmers in Burkina Faso may suffer from more severe bad weather shocks.

The idiosyncratic shock, ϵ , is estimated based on the work by [Kazianga and Udry \(2006\)](#). The authors explore the extent to which Burkinabé farmers can smooth income shocks through live-stock, grain storage and inter-household transfers. Relevant for this study is their decomposition of volatility of income into aggregate and idiosyncratic components. For both aggregate and idiosyncratic shocks in each of their six sample village, [Kazianga and Udry \(2006\)](#) estimate the ratio $\frac{\sigma}{\mu}$, where σ is the standard deviation of the shock and μ is the mean of the household income. The standard deviation of the idiosyncratic shocks, σ_ϵ , used to calibrate ϵ is derived by multiplying the

and Viceisza (2012) find that the method based on [Gneezy and Potters \(1997\)](#) yields fewer inconsistent answers.

⁷The CWSA module is designed by the International Research Institute for Climate and Society at Columbia University. It combines soil, crop phenotype, weather databases and management options to simulate crop reaction to water deficit. In particular, regarding weather data, it uses rainfall time series for more than 30 years, and daily evaporation data regarding the amount of soil moisture needed to optimize production. The simulations are based on the FAO estimates for the parameters that regulate crop growth cycle (the crop coefficients KC), its reactivity to water shortage during the different phases of this cycle (the varying yield response factors KY), and its sensitivity to the crops evapotranspiration (Seasonal KY). Finally, the potential sowing window is fixed to be constant across time and the soil water-holding capacity. This latter assumption plays a crucial role in ensuring that the crop model is influenced only by the rainfall distribution and not by other factors, such as farmer's ability to forecast the beginning of the rainy season, which would be instead captured in the idiosyncratic productivity term.

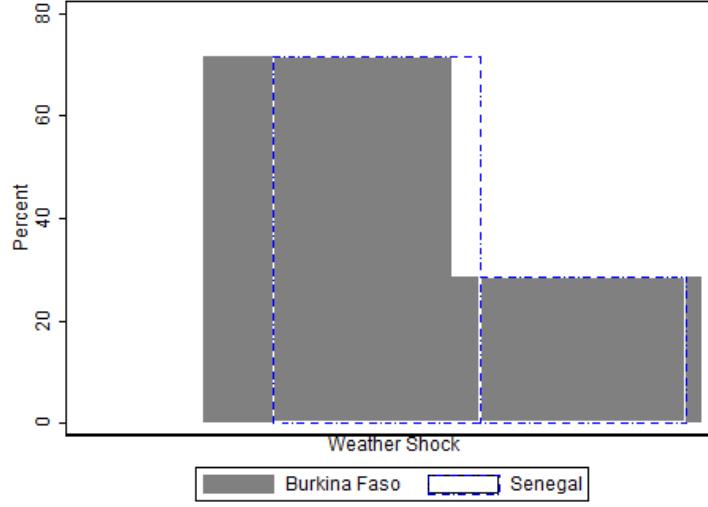


Figure 1: Distribution of the weather shock, η

ratio $\frac{\sigma_{idiosyncratic}}{\frac{\mu}{\sigma_{aggregate}}}$ from [Kazianga and Udry \(2006\)](#) by the standard deviation of the aggregate shock estimated by the CWSA module. Due to lack of data from Senegal, we apply the same procedure to derive the distribution of the idiosyncratic shock in Senegal. The idiosyncratic shocks in both countries are assumed to be lognormal distributed with mean one and standard deviation equal to σ_ϵ where σ_ϵ differ across countries because of the differences in σ_η .⁸ In Figure 2 we plot the distribution of the idiosyncratic shocks. Given that $\sigma_\eta^{\text{Senegal}} > \sigma_\eta^{\text{Burkina Faso}}$, Senegalese farmers are exposed to (slightly) higher idiosyncratic volatility.

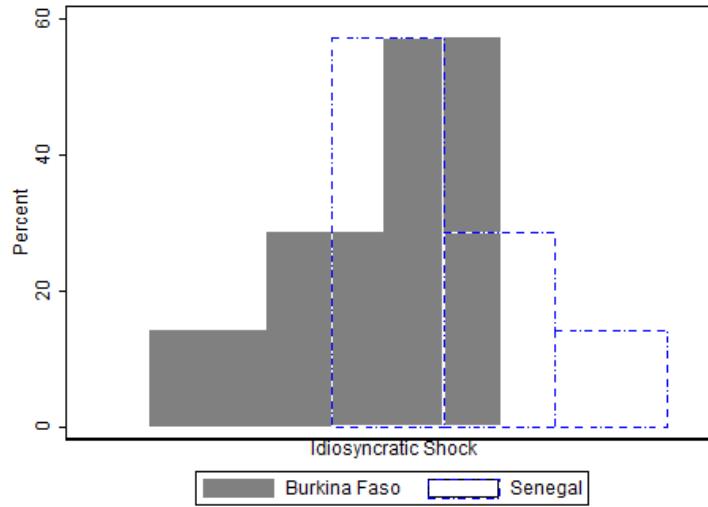


Figure 2: Distribution of the idiosyncratic shock, ϵ

Finally, we discuss the parameters that characterize each financial instrument detailed in Section 2. The premium of the index insurance contract is estimated based on the distribution of the

⁸The choice of the functional form relies on the evidence from [Claassen and Just \(2011\)](#). They find a reverse lognormal provides the best distributional fit for US corn yields once county-wide variation is removed.

weather shock, η . The final price of each unit of insurance policy is determined by the loading factor. In this study, the loading factor can take three distinct values: -10% , 0% , or $+10\%$. We assume a value for the design effect that arises from the fact that $\sigma_\xi > 0$ and the insurance payout are not perfectly correlated with the covariant shock experience by the farmers. Data on the likely magnitude of the design effect is hard to find, so if $\sigma_\xi > 0$ we assume that σ_ξ is about $0.15\sigma_\eta$ so that the correlation between losses and payout is 90%.

When we introduce the possibility of savings we set \mathcal{R}^a equal to 1.039 (1.04) in Burkina Faso (Senegal) which corresponds to one plus the average deposit interest rate paid by commercial or similar banks for demand, time, or savings deposits since 1990. This return is potentially generous in that, because of inflation, the real interest rate is almost one-tenth of the nominal return, 0.5% in Burkina Faso and 0.8% in Senegal.

The interest rate on debt, \mathcal{R}^d , is calculated as the average lending rate that usually meets the short- and medium-term financing needs of the private sector. Farmers in Burkina Faso and Senegal pay 16.25% interest rate on each unit they borrow. The interest rate on debt when default is feasible, $\widehat{\mathcal{R}}^d$, is derived by inflating \mathcal{R}^d with the insurance premium. The selected values are summarized in Table 1.

Table 1: Calibrated Parameters

	Burkina Faso	Senegal
Parameters	Value	Value
<i>Risk preferences</i>		
Discount factor, β	0.9	0.9
CRRA coefficient, ρ	1.39	1.39
<i>Production function</i>		
Capital share, α	0.35	0.32
Distribution of weather shock, η	Empirical distribution from CWSA	
SD of idiosyncratic shock, σ_ϵ	$0.97\sigma_\eta$	$0.97\sigma_\eta$
<i>Weather insurance</i>		
Loading factor, θ	10%	10%
Design effect, correlation(ξ, η)	90%	90%
<i>Savings</i>		
Interest rate on savings	3.9%	4.0%
<i>Credit</i>		
Interest rate on debt, \mathcal{R}^d	16.3%	16.3%
Probability of default if hit by the worst covariant shock, μ	90%	90%

4 Results

Under the benchmark calibration (Table 1), we solve the “baseline” optimization problem (1) and compute the optimal consumption and investment decisions in the absence of functioning financial

markets. We do this for both Burkina Faso and Senegal and find that the level of resources invested in the risk-free asset, a_t , and in the risky asset, k_t , is increasing in wealth, and that farmers invest more in risky farm production as they grow richer.

Based on the calibrated parameters, Senegalese farmers face a slightly less-productive but safer environment than Burkinabé farmers.⁹ As a result, investment is higher in Burkina Faso than Senegal, in the case of both risk-free assets and risky on-farm production. Conversely, consumption is higher among farmers in Senegal, at each level of wealth. Starting from these environments, we evaluate the impact of one financial instrument at the time by looking at its impact on wealth, consumption, risky-farm-investment and safe-investment over time. We also study the welfare implications from the provision of each financial products, both across level of wealth (for richer Vs poorer farmers) and over time (for the first generation of farmers that gains access to these new products Vs subsequent farmers' generations).

4.1 Impact on wealth, consumption and investment

We study the effects of offering the best insurance, saving and credit contracts for farmers. The contracts evaluated at the beginning of our analysis are unlikely available options, but they provide a benchmark for the level of welfare gains that may be achieved by investing resources for the development of index insurance and banking markets. Later we relax these assumptions and analyze the behavioral impacts of more “realistic” financial products that can be introduced. In particular, for each product we introduce the most common flaws that are not under the control of policy makers, and discuss the contracts’ details in the relevant subsections.

The analysis of each financial product is structured as follows. We solve for the policy functions that capture the optimal consumption and investment choices farmers make at each level of wealth owned. Using the policy functions from the baseline optimization problem 1 we compute the target level of wealth towards which farmers converge.¹⁰ We then initialize the impulse response functions at the target level of wealth under the baseline scenario and trace out the wealth, consumption and investment patterns farmers follow to reach the new steady state when one financial product is suddenly and unexpectedly introduced.

4.1.1 Weather insurance

First, we assess the impact from providing a weather index insurance contract (Equations 3) that (i) is not affected by basis risk, $\sigma_\xi = 0$, and (ii) is sold at the actuarially fair price, $\theta = 0$. *A priori*, the provision of insurance has an ambiguous impact on investment which can either increase or decrease it depending on the parameter values. On one hand weather shocks deter investment since they create uncertainty in the rate of return. But on the other hand, weather risk can stimulate

⁹This is potentially reflected in the labor decisions and value extracted from on-farm work. In Burkina Faso agriculture 90% of the labor force works in agriculture while this percentage drops to 77.5% in Senegal. Consistently, agriculture makes up for 34.4% (15.3%) of GDP in Burkina Faso (Senegal).

¹⁰The target level of wealth equals the level of wealth in the in the t^{th} period that corresponds to the expected amount in the following period $t^{th} + 1$.

investment through a precautionary motive as farmers may find optimal to over-invest in order to have enough income even in the case of negative weather shocks. Depending on the relative strength of these forces, investment can either fall or increase when insurance removes weather risk.

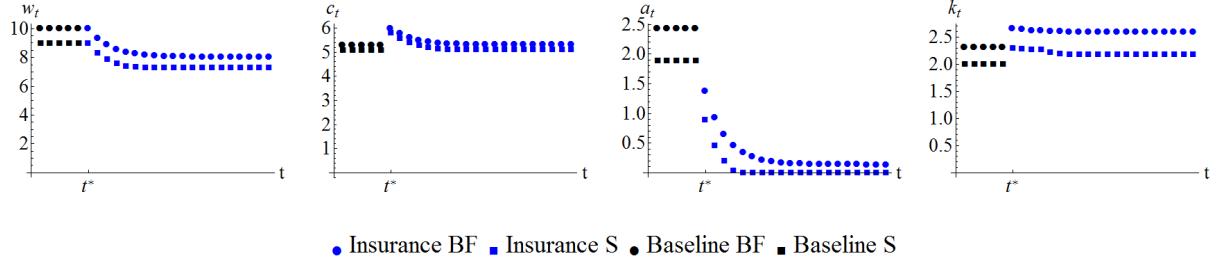


Figure 3: Impulse response functions from the provision of weather insurance contracts

In order to show which effect prevails we plot the impulse response functions in Figure 3. As soon as weather insurance becomes available in period t^* farmers increase their consumption, c , as well as their risky on-farm investment, k , but cut their precautionary investment in the riskless asset, a . Next period level of income, w , falls since the increase in consumption is not compensated by a sufficiently high increase in risky investment. Burkinabé and Senegalese farmers follow similar pattern, but the higher expected productivity in Burkina Faso allows farmers to enjoy higher consumption.

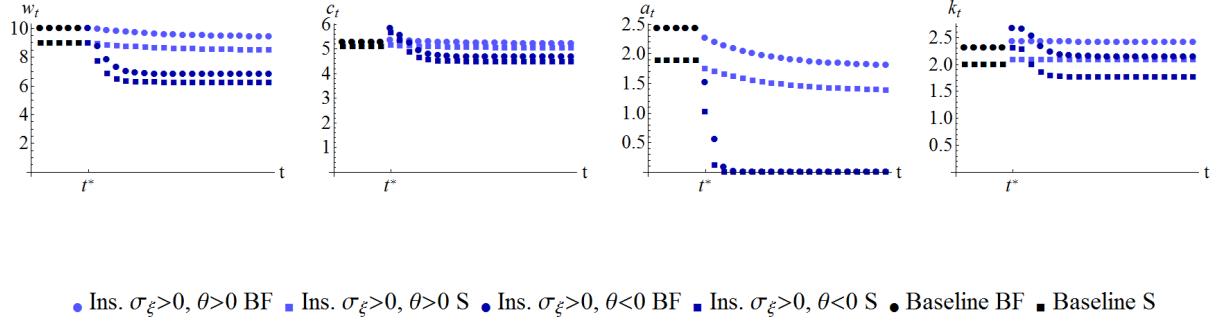


Figure 4: Impulse response functions from the provision of insurance contracts with basis risk

We obtain qualitatively similar results, once we introduce more “realistic” weather insurance contracts as indicated in Figure 4. These new weather insurance share a common feature: they are all affected by basis risk, $\sigma_\xi > 0$, an element that is unlikely to be eliminated in any empirical project.¹¹ Nonetheless we assume that insurance payout and farmers losses are fairly closely (90%) correlated, in order to understand whether minimal deviations from the optimal contract cause already significant welfare losses. Each contract is differentiated from the other by varying the insurance premium charged, from actuarially fair to actuarially unfair or favorable, that is the loading factor θ takes value +10% or -10%, that is we assume either a surcharge or a discount of

¹¹Precise estimate of basis risk are hard to find. Based on the limited data available, the estimates of basis risk for index insurance contracts offered range from as high as 75 to 90% (Carter (2012), and Chantarat et al. (2012)), to as low as 16% (Clarke (2011), based on the average level of basis risk present in 31 products actually sold).

10% on the actuarially fair premium. Imposing a positive or negative multiple on the insurance premium enables to mimic the potential evolution of the insurance market. A discount on the insurance premium is generally offered during pilot phases in order to encourage take-up among farmers and let them familiarize with the index insurance product that represents a complete novelty in the array of risk-mitigating options used by rural households. As the weather insurance market grows towards maturity, discounts are gradually eliminated and positive multiples are charged in order to cover the administrative costs related to the installation and monitoring of weather stations.¹²

4.1.2 Savings

Second, we introduce the possibility for farmers to access saving accounts so that they can earn positive return on the amount of riskless assets farmers set aside in order to hedge risk from one period to the next. Being fungible, such funds can indifferently be used against both covariant and idiosyncratic shocks. As anticipated (Table 1), we initially assume that farmers receive interest payment equivalent to the nominal interest payment made by formal banks in Burkina Faso or Senegal over the past 22 years (Figure 5).

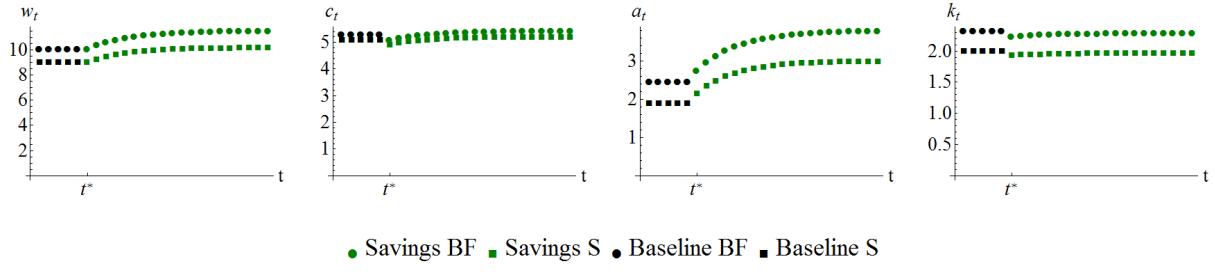


Figure 5: Impulse response functions from the provision of saving contracts

We later relax this assumption and take into account the presence of inflation and deflation (Figure 6).¹³ While both countries experience periods of inflation and deflation, the former were much more likely and more intense. As a result the real interest rate on deposit is on average 10 times smaller than the nominal interest rate paid over the time horizon considered (from 1990 to 2012).

Farmers increase the investment in the risk-free asset a_t as the return on investment becomes positive. As expected, they invest more when they can earn the nominal interest payments. The increase in a_t is financed by reducing the amount of consumption and investment in farm input. The increase in riskless investment more than compensates the contraction in risky investment

¹²Empirically we find that estimated loading factors vary between 10% of the actuarially fair premium for area-yield contracts in the United States up to 450% of the actuarially fair premium for some contracts in India.

¹³Price growth rates ranged from -21.7% (-28.8%) to +9.7% (+8.8%) in Burkina Faso (Senegal) since 1990. Our framework focuses on the short-run effects of policy interventions, considering only partial equilibrium impacts. Such price volatility indicates that the next step is to fully incorporate the role of price in the analysis. Under the current framework, price fluctuations are captured by shocks (idiosyncratic if markets are assumed to be highly segmented; covariant if farmers are assumed to face the same price).

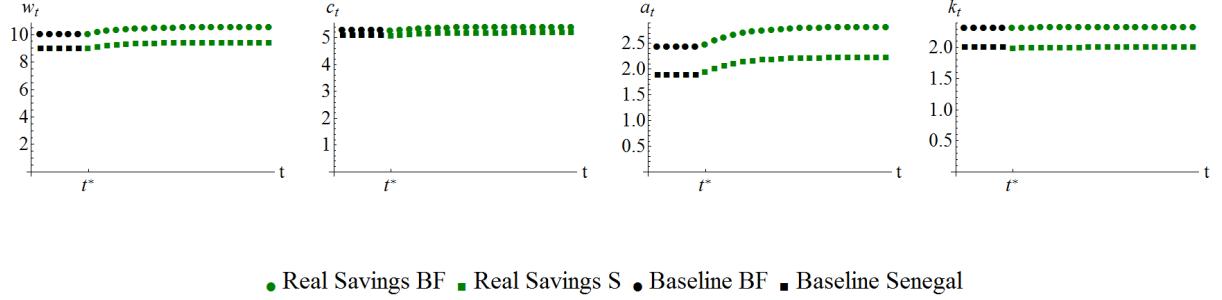


Figure 6: Impulse response functions from the provision of real-saving contract

and consequently farmers level of income increases over time allowing farmers to enjoy higher consumption after the initial fall. Results are similar in Burkina Faso and Senegal.

4.1.3 Credit

Last, we introduce the possibility to borrow for agricultural investment. Banks are typically reluctant to lend for agricultural investment as it would expose their loan portfolio to excessive risks. However, when banks are able to purchase weather insurance for each unit of capital lent they are potentially much more likely to extend loans to farmers. The probability of default is reflected in the increase in a higher interest rate (inflated by the cost of insurance paid for each unit of capital lent), but does not prevent farmers to access credit in the future. Under the more favorable scenario, we assume farmers can default on their loan with a certain probability μ (Equations 2.4); otherwise, default is not possible. Even in the best case scenario for farmers, default is not always possible as banks and farmers may observe different realization of the worst shocks, this is equivalent to assume that the contract offered to banks is affected by basis risks and that banks transfer this risk to farmers. With or without default, farmers implicitly face an upper bound on the amount of debt they can raise as they need to be able to reimburse the bank even if they are simultaneously hit by the worst idiosyncratic and covariant shock. This upper bound is higher when default is feasible.

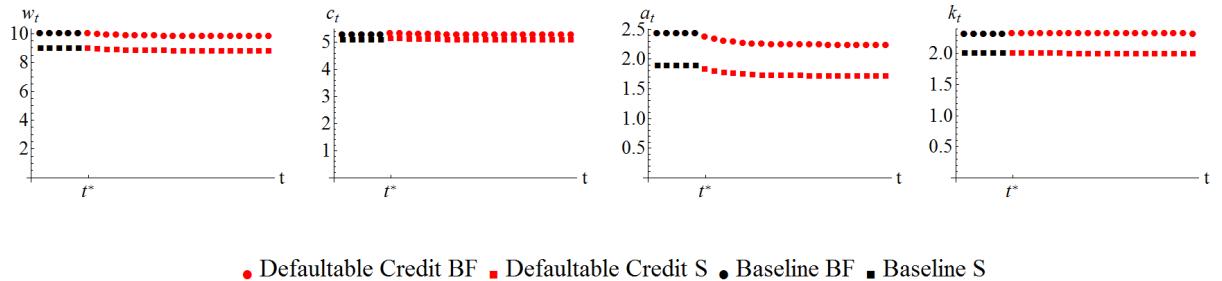


Figure 7: Impulse response functions from the provision of credit contracts

In Figure 7 we plot the impulse response functions when credit is insured. In Figure 8 we plot the impulse response functions when credit is not insured and default is no longer possible. The

availability of credit allows farmers to cut the precautionary savings in the zero-return assets, a_t and redirect their investment to farm production. Farmers become able to slightly increase their level of consumption. The contraction in precautionary savings is particularly pronounced when default is possible.

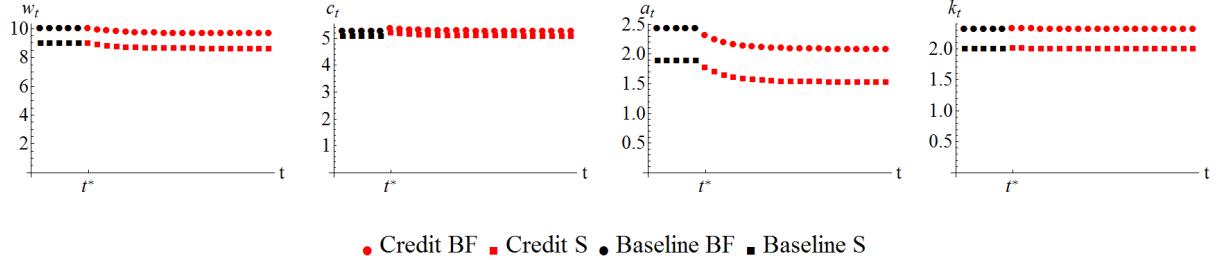


Figure 8: Impulse response functions from the provision of credit contract without the possibility of default

4.2 Impact on welfare

Finally, we evaluate the welfare impact from the aforementioned policy interventions. Welfare gains are defined as the permanent increase in consumption that would make farmers without weather insurance equally well off as farmers with weather insurance. Formally, they correspond to the χ_t such that $\mathbb{E} \sum_{j=0}^{\infty} \beta^j u(c_{t+j}^{\text{"baseline"}} (1 + \chi_t)) = \mathbb{E} \sum_{j=0}^{\infty} \beta^j u(c_{t+j}^{\text{"financial product"}})$. Given the properties of the CRRA utility function, this expression can be solved by taking the ratio of the respective value functions, so that the welfare gains can be expressed as $\chi_t = \left(\frac{V^{\text{"financial product"}}(w_t)}{V^{\text{"baseline"}}(w_t)} \right)^{\frac{1}{1-\rho}} - 1$. We compute welfare gains across wealth, comparing the value functions at each level of w . Exploiting the dynamic structure of the model, we also compute the welfare gains over time, by comparing the value functions evaluated at the target level of wealth implied by the different financial regimes.

In Figure 9 and 10 we plot the welfare gains that can be achieved in Burkina Faso and Senegal respectively.

Farmers gain more from the provision of index insurance (Figures 9a, 9b, 10a, 10b). Given the longer right tail of the η distribution, Burkinabé farmers gain more than their Senegalese counterpart from the provision of insurance. Subsidizing the insurance premium more than compensate the losses in welfare gains farmers suffer because of basis risk. Even when they have to pay an actuarially unfair premium, across almost all level of wealth, farmers are better off when insurance becomes available rather than when savings or credit becomes possible.¹⁴ The welfare gains from savings (credit) are increasing (decreasing) in the level of wealth. Poorer farmers benefit more from borrowing, even at the high \hat{R}^d , as credit allows them to grow faster towards the optimal level of on-farm investment. Conversely, richer farmers gain more from the possibility to earn a positive return on their riskless assets as, by definition, they own a larger amount of a .

The provision of savings leads to welfare gains that are increasing over time. Conversely, the provision of both insurance and credit leads to a decline in overall investment, by relaxing the

¹⁴Extremely poor farmers benefit more from the provision of credit rather than unsubsidized insurance or savings.

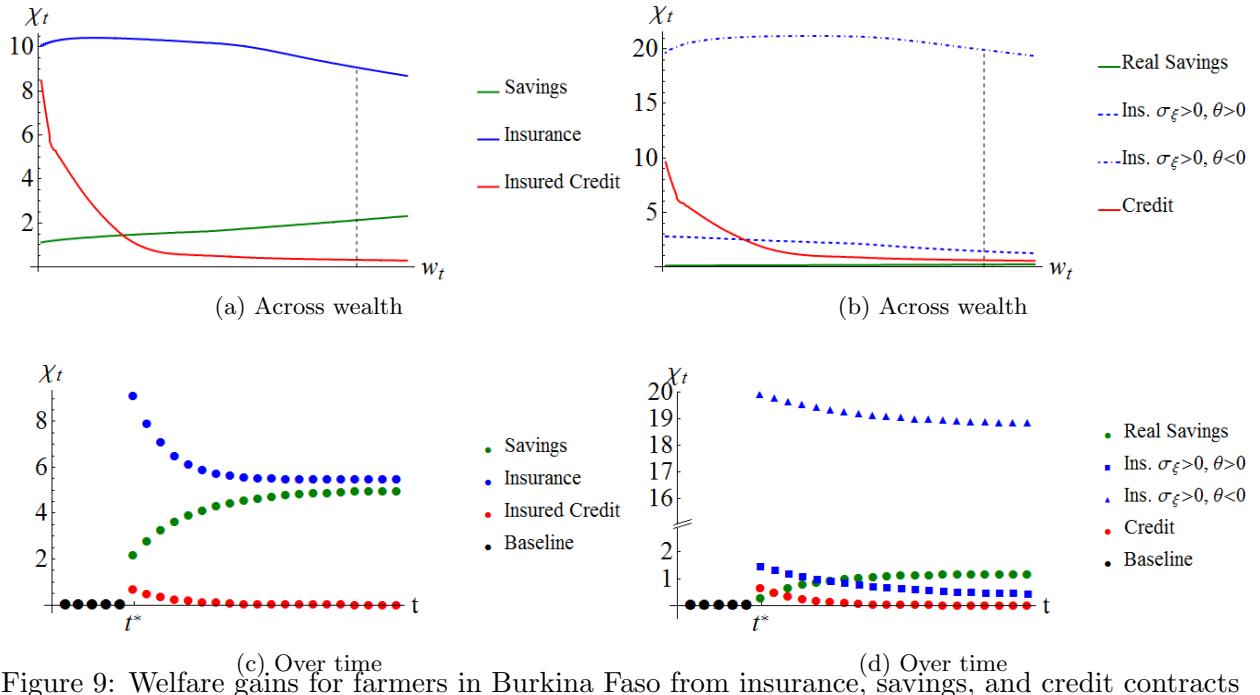


Figure 9: Welfare gains for farmers in Burkina Faso from insurance, savings, and credit contracts

precautionary motives behind over-investment when financial markets are absent. As a result, the level of welfare gains are declining over time (Figures 9c, 9d, 10c, 10d). The first generation of farmers gains more than the subsequent generations. It is worth noting that the results holds true under the assumption of infinite time horizon which corresponds to embedding full bequest motives. However, as long as future time periods are discounted ($\beta < 1$), as realistically one would expect, an increase in consumption today is more beneficial than the same increase at some later point in time.

5 Conclusions

Farmers in developing countries face severe uninsured production risks and consequently may largely benefit from the introduction of formal financial instruments that would help them to smooth consumption. In this paper we consider three separate policy intervention and examine their impact on consumption, investment and welfare. We start our analysis from benchmark scenarios and then progressively move towards more realistic policy interventions that incorporate the different limitations that each financial product carries.

The provision of weather insurance as well as credit leads to an increase in consumption and a decline in precautionary investment in riskless return-free assets. While qualitatively similar, these choices are quantitatively different as captured by the vast differences in the level of welfare gains that can be achieved. At each level of wealth, weather insurance enables farmers to achieve larger welfare gains which are decreasing in wealth. Over time, farmers gain less and less from the provision of these financial instruments due to the fact that the initial increase in consumption is not

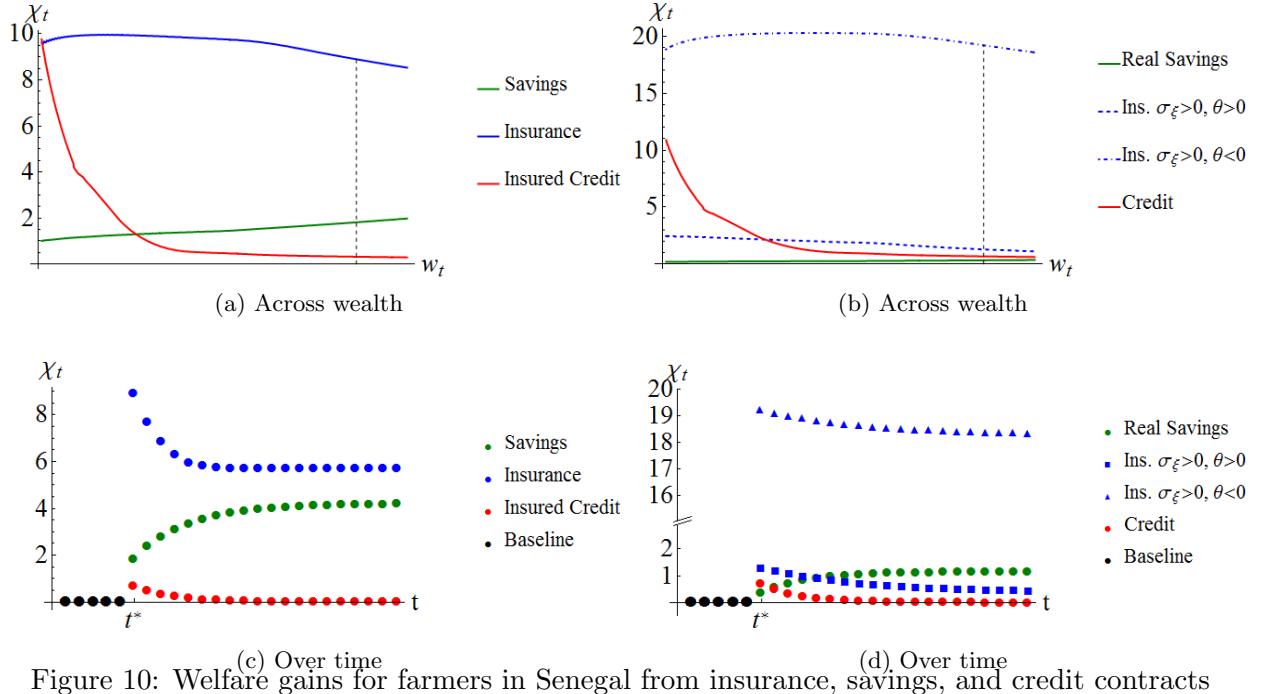


Figure 10: Welfare gains for farmers in Senegal from insurance, savings, and credit contracts

compensated by a sufficient increase in on-farm production. As we move away from the benchmark scenarios it becomes clear that welfare gains from weather insurance are highly sensitive to its pricing and that offering a relatively small discount (fee), substantially increases (cut) the benefits achievable by farmers.

The introduction of saving accounts on the other hand induces farmers to save more and eventually allows farmers to consume more. As a result the welfare gains are increasing both in wealth and over time. Richer farmers gain more as they can enjoy higher returns on larger endowments. The initial contraction in consumption combined with the increase in riskless investments leads to higher consumption in the future and consequently larger gains.

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