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Original Article

Application of Index Insurance in Iran's Agriculture: case of wheat growers

Aplicação do Seguro de Índice na Agricultura do Irã: caso dos produtores de trigo

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Abstract

Drought-induced risk endangers farmers in arid and semi-arid regions. Insurance is recognized as an appropriate policy alternative to support farmers facing with financial losses associated with production reduction. In this context, present study developed an *ex ante* index-based insurance program to deal with drought-induced risk of production losses. We applied this model to wheat growers in Iran. After the calibration of the contract parameters, an insurance scheme was optimized and tested. We showed that optimal insurance contracts generate low gain of certain equivalent income, high compensation, and a high basis risk. The best contract was not proportional to the complexity of the proposed index. The insurance program studied is recommended as a proper alternative for currently applying yield insurance.

Keywords: drought, index insurance, wheat, Iran.

Resumo

O risco induzido pela seca coloca em perigo os agricultores em regiões áridas e semiáridas. O seguro é reconhecido como uma alternativa política apropriada para dar suporte aos agricultores que enfrentam perdas financeiras associadas à redução da produção. Nesse contexto, o presente estudo desenvolveu um programa de seguro baseado em índice *ex ante* para lidar com o risco de perdas de produção induzido pela seca. Aplicamos este modelo aos produtores de trigo no Irã. Após a calibração dos parâmetros do contrato, um esquema de seguro foi otimizado e testado. Mostramos que os contratos de seguro ideais geram baixo ganho de certa renda equivalente, alta compensação e alto risco de base. O melhor contrato não foi proporcional à complexidade do índice proposto. O programa de seguro estudado é recomendado como uma alternativa adequada para a aplicação atual do seguro de rendimento.

Palavras-chave: seca, seguro de índice, trigo, Irã.

1. Introduction

Climate change has increased temperature and reduced precipitation during recent decade in most West-Asian countries including Iran, thus highlighting drought-induced risks of field crops. The exceptional drought of 2008 was associated with a severe lack of precipitation that noticeably damaged the wheat farms in most regions of the country (Bréda et al., 2006). The subsequent drought episode (2018) was even stronger in terms of intensity and area impacted (Buras et al., 2020). Damages due to extreme drought events include reduced growth, defoliation, and mortality. Loss in production may have substantial socio-economic impacts on farmers and rural areas. In response, Fuhrer et al. (2006) recommended that adaptive management strategies be implemented and that new agricultural insurance products be developed.

Several management-based strategies are proposed in order to improve the water consumption efficiency of farm products and, as a result, their resistance to drought risk. Reduction of density, reduction of rotation length, substitution by a better-adapted tree species, and stand diversification are among the most known adaptation strategies (Spittlehouse and Stewart, 2003).

Another widespread strategy consists of designing risk-sharing strategies through insurance products. In a context of international agreements encouraging countries to protect their farmers against the adverse impacts of climate change, recommendations have been made to use insurance as a vehicle to finance climate resilience and adaptation. In exchange for the payment of an annual insurance premium, the insured farmers receive an indemnity in case a disaster occurs.

Globally, the most common insurance program covers the risks of yield loss. However, the adoption of insurance is very different from one country to another. In Iran, the

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Agricultural Insurance Fund (AIF) as the sole agricultural insurer sells contracts compensating farmers for yield damage. However, the insurance coverage is relatively low and farmers are generally unsatisfied by insurance programs.

Very low penetration rates also characterize the German, Spanish, France and Slovakian markets. In countries like Denmark and Sweden, insurance against storm is a much more common practice with 68% and 90% of the private forest owners being insured (Brunette and Couture, 2008). Loisel et al. (2020) suggested several explanations accounting for these differences: mandatory insurance (e.g., Norway) vs. voluntary insurance (e.g., France), conditional public assistance (e.g., Denmark) vs. non-conditional assistance (e.g., France, Germany), objective of timber production in Northern countries vs. provision of non-market goods and services in France.

However, to our knowledge, no agricultural insurance contract offers to cover drought-induced risk of farm products in Iran. Traditionally, in the agricultural sector, drought is insured through an index-based insurance. However, because of climate change, drought has become a significant threat for the sector. Index insurance seems to be a relevant and well-adapted tool, since the index can be defined for different natural hazards such as extreme drought events. In this context, the objective of this paper is to develop and test an index-based (rainfall) insurance specifically designed to help Iranian wheat growers to cope with drought-induced risk. To this end, we developed an ex ante index-based insurance contract and simulated its effectiveness in terms of income smoothing capacity. We simulated the annual wheat farms productivity. We defined and compared different indices from the most simple ones, based on cumulative rainfall indices and the standardized precipitation index (SPI), to more complex ones based on water stress levels, the soil water stress index (SWS) (Guillemot et al., 2017). A series of simulations was performed to calibrate the insurance contract. Then, an optimal insurance scheme was optimized and tested. We showed that optimal insurance contracts generate low gain of certain equivalent income (CEI) and a high basis risk, and compensate a high part of losses. The best contract is not proportional to the complexity of the index. Finally, our preliminary results indicate that there is no clear advantage of differentiating contracts based on species.

The rest of the paper is structured as follows. The next section reviews relevant studies on agricultural index-based insurance. The material and the methods are presented in Section 3. Section 4 provides the results, which are discussed in Section 5. Finally, Section 6 concludes.

2. Literature Review

The literature on agricultural insurance covers a wide range of research topics. One topic deals with actuarial approaches that aim at determining insurance premiums, using different pricing methods. Holecy and Hanewinkel (2006) were the first researchers to propose an actuarial model serving as a basis for the calculation of premiums to cover the risk for either single or cumulative damaging factors in Germany. They proposed a minimum gross insurance premium of 0.77 EUR/ha for an insured area of 140,000 ha and a maximum premium of 4429 EUR/ha for an insured area of 14 ha of German forests. This study highlighted the important role played by the age of the stand and the total insured area in the calculation of the premiums.

Another field of research consists of application of the classical insurance economics model proposed by Mossin (1968) to farm management issues. Thus, Brunette and Couture (2008) developed a theoretical model to determine insurance demand drivers. This model shows the potential indirect impact of ex post public compensation after a disaster occurrence on the farmers' demand for insurance. Brunette et al. (2017a) proposed a theoretical "risk and uncertainty" model based on the impact of including adaptation efforts into insurance contracts on insurance demand. They showed that insurance could serve as an effective strategy when it comes to encouraging risk- and uncertainty-averse farmers to adapt to climate change.

Regarding to the index-based insurance literature, the principles of insurance based on meteorological indices were initiated by Halcrow (1948) and further developed by Dandekar (1977). These insurance schemes were initially proposed to help farmers cope with agricultural risks. They were mainly implemented in developing countries (Skees et al., 1999; Mahul, 2001) where limited infrastructures make low transaction costs contracts even more profitable for insurers and more valuable for insured.

Under index-based insurance contracts, farmers pay an annual premium and, in exchange, receive a monetary compensation when the index (calculated based on weather variables) goes beyond a threshold value. In the case of traditional insurance contracts, indemnity payments typically require that an expert observes and assesses the severity of crop damage after a disaster. This process induces an additional cost resulting in higher insurance premium and introduces asymmetry of information between the insurer and the insured farmer. In the case of index-based insurance, neither the principal (the insurance company) nor its agent (the insured farmer) have control over the meteorological data that are used to define the index. An observable index built upon meteorological data solves any moral hazard issue (Goodwin and Mahul, 2004), reduces transaction costs, and allows for a quick payment of the indemnity (Alderman and Haque, 2007). Moreover, indices allow for focusing on one risk independently of other conditions. Having a single index for a same given disaster and many contracts (and not for a specified risk and for a specific stand) also reduces the transaction costs and, thus, the insurance premium.

However, the main limitations of index-based insurance contracts arise from the imperfect nature of the index itself. Basis risk may become a concern when there are mismatches between income and index realization (Skees, 2003). The two types of basis risk are (i) when farmers receive an indemnity while they did not endure losses (type I), and (ii) when farmers endure losses without receiving an indemnity (type II). Imperfect insurance products characterized by high basis risk are typically associated with very low consumer demand (Clement et al., 2018).

The structure of the contract and simplicity of the index is also an area of challenge when it comes to advertising and selling such contracts. Keeping these considerations in mind, one of the objectives of present study is to develop and test multiple, increasingly complex indices.

We thus propose a new method, based on an ex ante index-based insurance, for coping with an increasing risk of drought-based yield loss. To our knowledge, this is the first study that deals with drought insurance in Iran and proposes an index-based insurance to cope with wheat yield loss. We tried to propose the proper actuarial approach, by simulating data to compute insurance premiums and optimal insurance contracts through an innovative method.

3. Materials and Methods

3.1. Insurance policy design

We designed our model with a simple framework with the following assumptions. First, the representative farmer aims to reduce the effect of drought risk on his product yield. Second, a private insurer offers the same contract to all representative farmers, regardless of their location. In order to compare the gain in terms of certain equivalent income (CEI), the utility with and without insurance was computed for each agent, through a constant relative risk aversion (CRRA) utility function and three different relative risk aversion coefficient (0.5, 1, 2). The agent purchases an insurance contract as long as the gain of CEI is positive.

3.1.1. Indemnity calculation

Indemnity was defined by three parameters according to the framework designed by Vedenov and Barnett (2004). The strike S is the threshold level of the index that triggers payoffs for insured farmer. The slope-related parameter λ (0 < λ < 1) determines the exit level (λ.S) from which payoffs are capped to a maximum M. All these elements are illustrated on Figure 1.

We thus have the following indemnity function depending on x, the observed level of the index:

$$(S,\lambda,M,x) = \begin{matrix} M \text{ if } x \le \lambda.S \\ \dfrac{S - x \text{ if } \lambda.S < x \le S}{S - \lambda.S} \\ 0 \text{ if } x > S \end{matrix} \quad (1)$$

3.1.2. Tested indices

To adopt the best index, we defined, tested, and compared different indices from the most simple ones (i.e., basic rainfall index) to more complex ones (i.e., drought index).

The first index is based on the cumulative precipitation during the growing season. We tested two types of cumulative rainfall: The three months cumulative precipitation (CP3) from June to August where the lack of water is the highest and the six months cumulative precipitation (CP6) from April to September, which corresponds to the entire wheat growing period in Iran.

The second index is the standardized precipitation index (SPI), which represents a slight improvement over the cumulative precipitation and is widely used to characterize meteorological drought. SPI quantifies observed precipitation as a standardized departure from the mean of the considered period. We calculated two different version of the index including the three-month SPI (SPI3) and the six-month SPI (SPI6) using the same time period as the one used for the computation of CP3 and CP6, respectively. However, while the SPI measures water supply, it does not take into consideration evapotranspiration, and thus, does not account for the effect of temperature on moisture demand and availability.

We therefore considered a more complex index, namely, the integrated annual soil water stress index (SWS) (Guillemot et al., 2017), which takes into account water supply (rainfall and soil water capacity) as well as water demand (canopy and soil evapotranspiration). The rationale for considering the SWS index is that wheat productivity depends on the availability of soil water to support plant growth. Indeed, soil water content has been shown to have low effects on plant metabolism up to a certain threshold

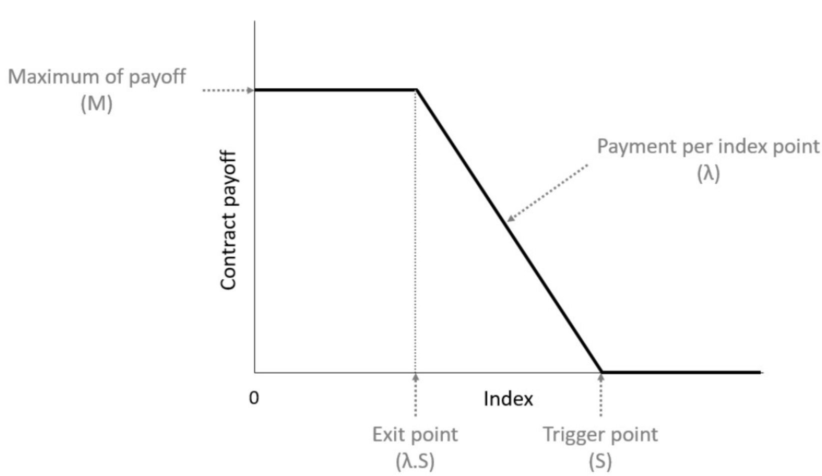

Figure 1. Payoff structure of an index-insurance contract (adapted from Vedenov and Barnett, 2004).

(Granier et al., 1999; Badeau et al., 2010; Breda and Badeau, 2008). To replicate the conditions under which plant starts regulating water consumption in order to grow and survive, we applied a 40% threshold on the available water content in the soil (AWC) (Lebourgeois et al., 2005).

3.1.3. Optimization of insurance scheme

First, we computed the income without insurance (W_0) and with insurance (W_{ins}) as follows:

$$W_0(t) = K_0 + w(t) \quad (2)$$

$$W_{ins}(t) = K_0 + (t) + (t) - p \text{ where } P = \sum_{0}^{T} \left(\frac{i(t)}{N/T} |(1+\tau \right)$$

where K_0 stands for the initial capital of the farmer, w is the income from wheat production of year t and i the indemnity of the year t. P is the annual premium, N the number of agents, T the time period and τ the loading factor, which represents administrative costs as well as the cost of the risk taken by the insurer (we assume an actuarially fair insurance, i.e., $\tau = 0$).

Due to the lack of data, we approximated the initial capital with the average income of past three years. Second, we used a CRRA utility function U to compute the variation of CEI. This function is commonly used in the literature to represent individual insurance behaviours (Sauter et al., 2016; Brunette et al., 2017b). The utility function and the CEI are computed as follows:

$$\left\{ U0\left(w0(t)\right) = \frac{W0(t)^{1-\rho}}{1-\rho} \quad \middle| UinsW\left(ins(t)\right) = \frac{Wins(t)^{1-\rho}}{1-\rho} \right\} \quad (3)$$

$$\left\{ \begin{array}{l} CEI(\overline{W0}) = \left[(1-\rho).EU(\overline{W0})\right]^{\frac{1}{1-\rho}} | \\ CEI(\overline{Wins}) = \left[(1-\rho).EU(\overline{Wins})\right]^{\frac{1}{1-\rho}} \end{array} \right\} \quad (4)$$

where EU($\overline{W0}$)the expected utility of the vector of income realizations without insurance, EU($\overline{Wins}$) the expected utility of the vector of income realizations with insurance, and ρ the relative risk aversion coefficient as defined by Arrow-Pratt.

Finally, we optimized the contract parameters (S, λ, M) in order to maximize the CEI for each index. Rothschild and Stiglitz (1976) demonstrated that the differentiated contracts could reduce the asymmetry of information, in particular the adverse selection, compared to a unique contract.

3.2. Data

In our statistical models, we used annual data on wheat yield and rainfall for the period 1971-2021. Data are adapted from different statistical yearbooks and online databases from Iran's Ministry of Agriculture and Meteorological Organization. Time-series feature of data are assessed by different stationarity tests available at econometric software.

4. Results and Discussion

Table 1 shows the parameters of the optimal insurance contract (S, λ, M), the gain of CEI with insurance (CEIins) compared to the initial one (CEI_0), and the annual premium for the baseline contract for each tested index. The results are presented for a relative risk aversion coefficient of 1 corresponding to the estimated coefficient of Iranian wheat growers. Table 1 shows that all contracts are different from each other depending on the considered indices. The contract maximizing CEI is provided by SWS regarding the relative risk aversion coefficient. We can see that gain in CEI are very low. Gain in CEI decreases with the type II basis risk.

To assess the interest of an index and compare them, we computed three criteria. The first one is the part of financial losses compensated by indemnity. The second criterion is the part of basis risk, type I and type II. The last criterion is the part of real losses that are compensated, i.e., the number of cases when the index perfectly matches the loss of income. The results of these three criteria are presented in Table 2 for a relative risk aversion coefficient of 1.

Table 2 shows the variability in terms of the percentage of loss compensated by indemnity, going from 26.6% (with SWS) to 99.5% (with SPI6). However, we can see that large percentages of loss compensated by indemnity is linked to a high type II basis risk (close to 50% of the cases). Six-month indices (CP6, SPI6) present higher losses compensated, a lower type I basis risk, and a higher type II basis risk than three-month indices (CP3, SPI3). The more complex index, SWS, shows lower losses compensated, a higher type I basis risk, and a lower type II basis risk than the other indices.

The heterogeneity of optimal insurance contracts shows the importance of testing different indices and considering different parameters (e.g., relative risk aversion coefficient) (Table 2). However, a common result is the low gain in CEI (Table 2). Leblois et al. (2014) also demonstrated this result after testing an ex ante insurance model for agriculture. Their low gain might be explained by the cost associated with the implementing such insurance policies (Leblois et al., 2014). Here, our low gain are probably the result of a high basis risk (Clement et al., 2018).

SWS provides the best contract for both the baseline and proposed index-based contract, but with the lowest gain in CEI, the highest premium, and the lowest percentage of loss compensated by indemnity. Additionally, while an index like SPI provided almost full compensation of lost income, this was associated with a large percentage of loss not compensated by an indemnity (type II basis risk) (Table 2), which is the worst risk between the two basis risks, because it undermines the credibility and sustainability of the system.

The type I basis risk, which can induce a higher premium, was low in our results (Table 2). There is a trade-off between having a strong correlation between the index and the losses and having a large percentage of compensated losses.

Our results are based on a first approach that will be improved by taking the following steps.

Table 1. Parameter estimates of the index- based insurance scheme.

Scheme	Index	CEI_0 (USD)	CEI_{ins} (USD)	S	λ	M	Gain	Premium (USD)
Baseline	CP3	3122.30	3125.94	141.7	0.1	0.5	0.117	67.39
Contract	CP3	2737.89	2740.49	231.7	0	0.3	0.095	119.63
Baseline	CP6	3122.30	3124.05	323.5	0	0.6	0.056	43.42
Contract	CP6	2737.89	2739.51	453.5	0.1	0.3	0.059	90.95
Baseline	SPI3	3122.30	3123.57	3.1	0	0.3	0.041	45.42
Contract	SPI3	2738.76	2738.76	3.0	0.2	0.2	0.032	34.40
Baseline	SPI6	3122.39	3122.39	0.6	0.9	0.3	0.003	1.42
Contract	SPI6	2737.89	2738.07	1.3	0.1	0.3	0.007	3.64
Baseline	SWS	3122.30	3130.21	133	0.3	0.6	0.254	201.40
Contract	SWS	2737.89	2745.58	143	0.2	0.6	0.281	139.59

Values are converted from Iranian Rial to USD.

Table 2. Baseline and estimated percentage losses.

Scheme	Index	Comp_loss	BR_I	BR_II	Real_loss
Baseline	CP3	76.1	9.6	34.6	19.7
Contract	CP3	75.7	14.5	19.4	58.3
Baseline	CP6	84.6	9.4	37.3	17.0
Contract	CP6	81.5	13.8	23.2	54.5
Baseline	SPI3	83.9	14.0	32.1	22.3
Contract	SPI3	93.0	6.5	50.7	27.1
Baseline	SPI6	99.5	0.1	54.1	0.2
Contract	SPI6	99.3	0.5	76.0	1.8
Baseline	SWS	39.7	21.6	15.6	38.8
Contract	SWS	59.1	12.8	17.2	60.6

First, the insurance premium is typically higher than the expected indemnity. Indeed, our insurance model was based on an actuarially fair insurance. The most common insurance economics literature (Mossin, 1968; Dai et al., 2015) shows that unfair insurance premium reduces the level of insurance. We can thus expect that applying a loading factor of 10%, as studied by Brunette and Couture (2018) and Loisel et al. (2020), will increase insurance premiums and reduce the level of insurance.

Second, insurance contracts could be adapted to the context of increasing risk linked to climate change. This would prevent the price of premiums from increasing over time (resulting in fewer insured on the market), and thus, maintain the viability of the insurance system. Indeed, the system should only give indemnity for high damage but for few cases. The definition of index level for exceptional drought events needs to be flexible and compensate insured owners less frequently but for more severe damages. To test such contracts, the index and insurance contract simulations should be performed under different climate change scenarios using a variety of global climate predictive models.

5. Concluding Remarks

The Agricultural Insurance Fund (AIF) is the sole insurer acting in the Iran's agriculture sector since 1993. Its insurance schemes are simple and far from the modern alternatives available in developed nations. Therefore, move into modern index-based insurance products is inevitable.

Insurance contracts are exclusively provided by AIF insurance agents across the country. The small percentage of insured farmers shows the need to develop new and suitable insurance products, especially in a context of accelerating climate change. To prepare for increasing drought-induced risk, index-based insurance contracts may provide a valuable risk management tool to compensate farmers for financial losses.

The innovative aspect of our study was to investigate an ex ante index-based insurance model for wheat (as the main strategic crop) growers in Iran. We showed that optimal insurance contracts are associated with low gain in CEI and provide high compensation and high basis risk. This preliminary study will be improved, in particular with the inclusion of future climate data.

This study offers several directions for future research pertaining to farmers' adaptation to climate change. Insurance contracts can serve as incentives for farmers (Brunette et al., 2013, 2017a, 2019), especially those who do not sufficiently use traditional practices to adapt to climate change (Davi et al., 2005; Cheaib et al., 2012; Brunette et al., 2015; Deng et al., 2015; Andersson and Keskitalo, 2018). Lower indemnity (or higher premium) in case of damage may further encourage wheat growers to adopt new management practices.

Finally, drought induces long-term damage resulting in severe risk of production loss, which may be associated with secondary risks such as pest attacks (Desprez-Loustau et al., 2006; Davi and Cailleret, 2017) and fire (Subak, 2003; Stephens et al., 2018). As soon as observed data will be available, we will have the possibility to test our model using composite indices that are able to handle greater degrees of complexity. Additionally, insurance contracts can be a way to cope with multiple related risks. The development of insurance contracts for dependant risks, such as drought and fire, should be investigated (only insurance contracts for independent risks are currently available: storm and/or fire).

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