

## Proposal for Securitization of Systemic Risk in Slovak Agriculture<sup>1</sup>

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### Abstract

*The article proposes insurance of agricultural crop represented by hectare yield in Slovakia. There is a systemic risk, for which the fund from collected premiums may not be sufficient for the insurer. It therefore seeks reinsurance in the reinsurance market. If it is exhausted, the reinsurer transfers the unbearable part of the risk to the capital market by means of ILS instruments, namely CAT bonds. The indicator of a loss event is the value of the loss index. The diverse geographical relief of Slovakia causes different conditions for farmers to grow crops, in our article we took wheat. Different hectare yields are achieved due to different geographical conditions in the same production process. This causes a balance distortion between the amount of the same premium and the amount of the risk borne and the existence of a basis risk. Due to its elimination, we will divide growers according to cultivated land into agricultural production areas, where the achieved hectare yields are registered, and we will evaluate CAT bond for each of them. The risk is then transferred to the capital market. For a securitization process to be feasible, the tradability of a CAT bond is essential.*

**Keywords:** *systemic risk, securitization, catastrophe bond, production areas, basis risk*

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## Introduction and Motivations

The risk in agriculture is significantly greater than in other sectors of the national economy. The weather, the incidence of diseases and pests, as well as climate change have an increasing impact on agricultural production. This high risk affects the income, investment and hence the competitiveness of farmers. It is therefore essential that risk management tools are available at the highest level. High-quality strategies can thus strengthen the farmers' ability to absorb, react or survive unexpected situations. A truly functional system requires close cooperation at all levels from farmers to food industry, trade and financial institutions and the insurance companies.

It is the process of insurance in agriculture in crop production that is complicated here. Some insurance companies operating on the Slovak insurance market offer only coverage of risks arising specifically from adverse weather effects or pest infestation. For example, Generali, a. s. provides insurance for quantitative loss of crops due to hail, natural elements, winter and spring frosts, deposited costs. The Agricultural Paying Agency pays up to 80% of the insurance premium. Allianz – Slovenská poisťovňa, a. s. provides insurance coverage for hail, storm, flood, fire, cloudiness, wintering. This goes similar with Agropoisťovňa a. s. and other insurance companies. Insurance companies specialize in voluntary contract insurance. The offer of insurance products in the insurance market is limited since private insurance companies do not insure all risks and namely these insurable risks can cause a widespread damage to agricultural production. Since 1991, insurance has been on a decline, which is related to a decline in agricultural production as well as lower interest from businesses to use insurance products. Similarly, the tendency of data about insurance premiums paid by agricultural holdings and compensation paid by private insurance companies does not speak in favor of insurance. According to Chrastinová (2016, p. 6) in year 2000, damages covered almost 60% of the premium paid, in 2016 it was only 40%. Therefore, the offer of insurance products related to agricultural production needs to be complemented by some others. The aim of this paper is to submit a proposal for a new type of crop insurance. The insurance premium will be based on the achieved per hectare yield of the agricultural crop measured in tonnes per hectare. Since farmers work under different conditions the harvest is affected by them. We will take into the account the acceptable conditions later in the insurance.

Agricultural crop insurance based on yield per hectare is still absent from the Slovak agrarian insurance market. In order, for such an insurance process to be feasible, it is necessary to firstly solve the problem of a possible insolvency of the insurance company. The classic approach is to seek reinsurance in the reinsurance

market. But even this market has its capacities limited. If the reinsurance market reserves are exhausted, free capacities in the capital markets are sought through securitization.

This process is referred to as an alternative risk transfer that pushes the risk threshold and which the insurer in cooperation with the reinsurer is able to cover it. Reinsurer's tools to achieve this aim are Insurance-Linked Securities, shortly called ILS. Capital market participants is able to absorb risk that is beyond the limits of insurers and reinsurers, Cummins and Weiss (2009 p. 538). While the reinsurer, in cooperation with the ILS issuer, is seeking to compensate his loss by lowering the payout from these securities, investors expect high returns and at the same time non-correlation with their other assets held in their own portfolio caused by portfolio diversification. A financial product with a payout directly dependent on the reinsurer's loss can meet the investor's requirements but poses a threat of moral hazard stemming from the ability to manipulate with the per hectare yield, thus with the data determining the securities payout. This threat can be reduced by modifying the ILS payout definition. Another measure is that the securities payout should depend to some extent on some neutral quantity e.g. on a predetermined loss index value. The loss index is calculated from aggregate losses of policyholders. The imperfect positive correlation of individual policyholders' loss with the loss index value is a source of basis risk, which may result in some cases in failure of ILS payout to compensate the reinsurer for his loss. A perfect positive correlation would eliminate the basis risk but is difficult to achieve. However, basis risk can be solved to some extent by aligning technical parameters of the insurance contracts with the loss index calculation. Thus, in order to be able to provide the agricultural crop insurance, the above-mentioned problems need to be successfully addressed.

## **1. Literature Review**

Insurance markets are undergoing transformation as new risk management strategies and new financial instruments are being developed to complement or replace traditional insurance or reinsurance products. Traditional insurance instruments insure partial risks that can be correctly quantified. Modern strategies propose to deal with insurance risk along with greater ability to pass the unwanted risk on to other entities. Risk analysis was addressed by Doherty and Schlesinger (2001, p. 48). They showed that in the case of an existing correlation between the risks of individual participants, the best way to share risk is to break it down into a diversifiable and non-diversifiable part. While the diversifiable part is fully insured by mutual insurance between policyholders, the non-diversifiable

risk is transferred to the reinsurer. Securitization consists of the distribution and redistribution of non-diversifiable risk. Unlike traditional reinsurance, they have stated that securitization allows the transferred risk to be divided into more manageable parts. They proposed to spread the catastrophic risk in non-life insurance into multiplicative components. Their approach is progressive, but it requires the existence and functionality of a market with future contracts, which is absent from the Slovak market.

The case of insurance and reinsurance market capacities exhaustion is addressed by Cummins and Weiss (2009, p. 494). When the reinsurance market reserves are exhausted, free capacities in the capital markets are sought through securitization. They refer to this process as an alternative risk transfer that pushes the risk threshold and which the insurer – in cooperation with the reinsurer – will be able to cover. The reinsurer's instrument to achieve this goal is insurance – linked securities, known as ILS. Capital market participants are able to absorb risk beyond insurers and reinsurers. Another aspect in favor of securitization versus reinsurance is, according to Barrieu and Albertini (2009, p. 73), the tradability of the securitized risk and also the fact that the payouts from ILS products have high expected returns and are independent of the returns of the assets held in their portfolios. Thus, they have a positive impact on the diversification of the portfolio held.

In many works, we mention just few e.g. Woodard and Garcia (2008, p.112), Rao (2010, p. 197), investigate geographic base risk, manufacturing base risk, and hedging with weather derivatives. The data for the presented results, relate to the states of the USA and India incomparably larger than Slovakia.

In the European region, namely Italy, the impact of climate change on insurance contracts is discussed by Fusco, Miglietta and Porrini (2018, p. 13). Liu and Ker (2019, p. 9) address the importance of data for the creation and valuation of insurance products offered by the Federal Crop Insurance Program operated by the United States Department of Agriculture's Risk Management Agency (RMA). It excludes older data prior to 1991 due to significant innovations in farm management technology and addresses probability tail estimation.

The introduction of catastrophic bonds to reduce the exposure of systemic risk to insurance companies was dealt with by Vedenov, Epperson and Barnett (2006, p. 322) for cotton in Georgia, USA. CAT bond contracts are based on percentage deviations of yields from the national long-term average. The main contribution of the article is the mechanism of crop risk transfer to insurance companies.

The article follows exactly the approach of compensating farmers in case of poor harvest. It takes into the account the quality of cultivated land, which affects

the size of the per hectare yield production. Differences in agricultural conditions must be taken into the account in crop insurance. It is not of our knowledge whether different conditions resulting from different soil quality have been taken into the account so far.

## 2. Theoretical Basis

Let's consider a group of mutually independent policyholders, holding risk of the same kind i.e. bound by the same probability distribution, and let's consider that a damage event for one policyholder is not affected and does not affect the occurrence and amount of the loss for any other policyholder. Policyholders participate in the creation of a common fund designed to compensate for losses that is managed by the insurance company. If the compensation tends to exceed the value of the common fund formed by payments of insurance premiums and yields from financial assets of the insurance company, a threat of insurer's insolvency arises.

The insurer seeks to address this thread signing up a suitable reinsurance contract with a reinsurance company. Let  $A$  be the amount of loss covered by the insurance company and  $M$  the loss determined in the reinsurance contract as the upper limit for loss coverage. If the reinsurer has a contract agreed in this way and there is no risk of default, then payments  $P_T$  are secured to the ceding insurance company at the expiry date  $T$

$$P_T = \begin{cases} M - A, & \text{if } C_T \geq M, \\ C_T - A, & \text{if } M > C_T \geq A, \\ 0 & \text{else} \end{cases} \quad (1)$$

where  $C_T$  are aggregated catastrophe losses of the ceding insurance company at time  $T$ . The reinsurance contract constitutes in fact the range of two European call options with two different implementation prices.

We will consider the risk of default in case when the reinsurer is unable to meet his obligations towards the ceding insurance company. In this case, the reinsurer must adjust the payments under the reinsurance contract regarding its assets and liabilities.

Let  $V_{A,T}$  represent assets and  $V_{L,T}$  liabilities of the reinsurer. As mentioned in Lee and Yu (2007, p. 14) the reinsurance company would then be forced to adjust the payments  $P_{def,T}$  from the reinsurance contract according to (2).

In this case the reinsurance company is at risk to lose its reputation and position on the reinsurance market.

## 2.1. Cash Flows in Reinsurance and Securitization

As the reinsurance company does not lose its reputation and position in the reinsurance market, it will seek to expand its reinsurance capacities by an alternative transfer of the insurance risk.

$$P_{def,T} = \begin{cases} M - A, & \text{if } C_T \geq M \text{ and } V_{A,T} \geq V_{L,T} + M - A, \\ \frac{(M - A)V_{A,T}}{V_{L,T} + M - A}, & \text{if } C_T \geq M \text{ and } V_{A,T} < V_{L,T} + M - A, \\ C_T - A, & \text{if } M > C_T \geq A \text{ and } V_{A,T} \geq V_{L,T} + C_T - A, \\ \frac{(C_T - A)V_{A,T}}{V_{L,T} + M - A}, & \text{if } M > C_T \geq A \text{ and } V_{A,T} < V_{L,T} + M - A, \\ 0, & \text{else} \end{cases} \quad (2)$$

With securitization the insurance risk is being transferred to capital market entities by means of specific securities called ILS (Insurance-Linked Securities). The ILS payout is defined appropriately to compensate for the insufficient reinsurer's capacity, thereby smoothing out cost fluctuation. Reducing the risk of a critical loss and a subsequent insolvency is thus the primary reinsurer's motive to choose securitization. Financial flows resulting from ILS for the period  $\langle 0, T \rangle$  are presented according to Pinda and Smažáková (2017, p. 12) in Figure 1.

The reinsurer, in addition to the reinsurer premium paid by the insurance company, will obtain the financial flow from his issue of ILS securities and its subsequent sale through sales agents to the investors operating in the capital markets. Thus, ILS contributes to the diversification of the investor's portfolio, which is for him essential. These securities provide the kind of diversification that can be achieved with no other securities Krutov (2010, p. 501).

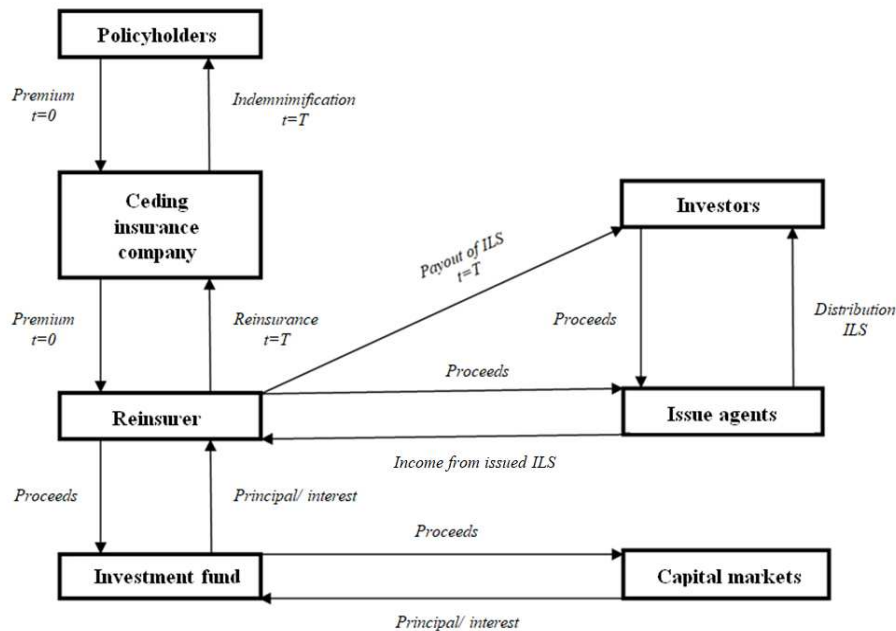
The crisis in 2008 also showed that when almost all securities were losing value, including those with historically lowest mutual correlation, ILS were still developing independently. A secondary motivation for buying ILS is their above-average yield. Another aspect that favors securitization before choosing reinsurance is, according to Barrieu and Albertini (2009, p. 31), the tradability of the securitized risk. The investor as a risk bearer is not tied to the insurer and can sell ILS on the secondary market. In this way, the reinsurer obtains reinsurance capital plus capital from the ILS sale, whereby he creates a financial fund and valorizes it on capital markets until due date  $T$ .

The most used securitization tool in a long-term perspective is the catastrophic bond (CAT bond). Unlike a standard bond, its payout depends on the occurrence of an event that correlates with the insurer's critically high claims.

When the specific catastrophic event occurs by the due date  $T$ , the disaster bond payments are lowered or fully cancelled. Then we are talking about bond triggering. The reinsurer will save some part of his capital originally intended to pay off the bond. He uses these financial means to cover the claims towards policyholders. When a bond is not triggered, the investor profits from an above-average yield. The reinsurer has a loss towards the investor, but this loss is covered from the reinsurance premium.

Figure 1

### Financial Flows in the Securitization Process



Source: Author's own work.

Catastrophe event triggering the CAT bond is quantified by trigger  $L_T$  and its threshold value  $D$ . The pay-off for the non-coupon  $V_T$  catastrophic bond by due date  $T$  with nominal value  $F$  is according to Komadel, Pinda and Sakálová (2018, p. 9), Pinda and Smažáková (2017, p. 12) and other authors defined by

$$V_T = \begin{cases} R_F \cdot F & \text{for } L_T > D, \\ F & \text{for } L_T \leq D \end{cases} \quad (3)$$

where  $0 \leq R_F < 1$  is the pay-off lowering coefficient. In case  $R_F = 0$  the pay-off is fully eliminated. For  $R_F = 1$  it is a case of a classical discounted bond with zero coupon. Expected bond pay-off  $E[V_T]$  from (3) with the expectation operator  $E$  is

$$E[V_T] = F \cdot P(L_T \leq D) + R_F \cdot F \cdot P(L_T > D) \quad (4)$$

Bond purchase price  $V_0$  is determined by expected return  $r(t)$  required by the investor regarding the risk level of investment. In case the expected return is constant  $r(t) = r$  during the entire bond lifecycle, for purchase/selling price  $V_0$ , it hold

$$V_0 = e^{-rt} E[V_T] \quad (5)$$

A trigger in a catastrophe bond may be a particular loss of an individual or a value of a loss index calculated in a predetermined procedure. In the article we will apply theoretical knowledge to the specific insurance of agricultural crop loss. We will also take it into account different natural conditions of farmers by classifying them into production areas with different achievable crop sizes for a selected agricultural crop.

Let us suppose that  $p$  farmers cultivate a specific crop within the national agriculture. Crop size of  $i$ -th farmer in year  $t$  is representing his reached hectare yield denoted as  ${}^i y_t$ , usually measured in tonne on hectare ( $t/ha$ ). On the contrary to the loss index definition as stated in Vedenov, Epperson and Barnett (2006, p. 323) we define  ${}^i L_{n,t}$  as

$${}^i L_{n,t} = \frac{\bar{y}_{n,t} - {}^i y_t}{\bar{y}_{n,t}} \quad (6)$$

what should be interpreted as a relative loss of  $i$ -th farmer in year  $t$  by the ratio of relative loss of this year's yield with the  $n$ -year national average  $\bar{y}_{n,t}$  reached in year  $t$ , which we held to be transparent for all insurance and reinsurance process participants. A loss event of an  $i$ -th farmer happens in case  ${}^i L_{n,t}$  crosses a threshold value  $D$ , i.e.

$${}^i L_{n,t} > D \quad (7)$$

From formulas (6) and (7) it is obvious that the farmer can raise claim at the insurance company, whereby for his yield it hold

$${}^i y_t < (1 - D) \bar{y}_{n,t} \quad (8)$$

As stated above, a situation can occur to the insurance company that the value of aggregated insurance claims exceeds the fund created by the insurance company from the farmer's paid premiums. In case of a reinsurance contract between the insurance and reinsurance company the insurance company expects financial coverage from the reinsurance company for all uncovered losses. The reinsurance company expects some financial capital from initiating catastrophe bonds;



however, this is bound to the trigger value calculated from reached annual hectare yield  $y_t$  for year  $t$  and average hectare yield. Therefore, the trigger of catastrophe bond  $L_{n,t}$  is calculated by

$$L_{n,t} = \frac{\bar{y}_{n,t} - y_t}{\bar{y}_{n,t}} \quad (9)$$

An average hectare yield of  $i$ -th farmer categorized in some of the production areas  ${}^i y_t$  for year  $t$  does not have to be identical with the state average hectare yield  $y_t$  for year  $t$ . This potential disproportion constitutes a so-called basis risk. This may cause the policyholder's legitimate claims that exceed the value of the collected premium fund do not have to be necessarily covered due to non-triggering of catastrophic bonds. Thus, a source of basis risk is the inequality of trigger values calculated according to the achieved hectare yield of an individual assigned to his respective production area and according to the national hectare yield. Like in Lee and Yu (2007, p. 269) let us define as

$$\delta(L_T) = F - V_T \quad (10)$$

If the relative loss of the  $i$ -th farmer is identical to loss index  ${}^i L_{n,t} = L_{n,t}$  calculated according to the national average yield, which is also the bond trigger and bond payout is the same according to (10), so the basis risk does not arise in the securitization process and must necessarily apply  $\delta({}^i L_{n,t}) = \delta(L_{n,t})$  for  $i = 1, 2, \dots, p$ . In opposite case, when  $\delta({}^i L_{n,t}) \neq \delta(L_{n,t})$  the basis risk does occur and creates some speculation options to accept policy claims, which we can label as moral hazard. To be able to analyse the basis risk we need to set the bond selling price or eventually the expected bond pay-off depending on the trigger value  $L_{n,t}$ , threshold value  $D$  and pay-off reduction coefficient  $R_F$ . From (4) we see that we do not need to necessarily know the distribution density for loss index  $L_{n,t}$ . For density estimation we will use a kernel approach mentioned in the article Vedenov, Epperson and Barnett (2006, p. 324) in the form (11) where  $L_i$ ,  $i = 1, 2, \dots, m$ , are relative national losses from previous  $m$  years,  $K$  is Epanechnik's kernel function and  $h$  is a smoothing average. By procedure described in Komadel, Pinda and Sakálová (2018, p. 135)

$$\hat{f}(L_{n,t}) = \frac{1}{mh} \sum_{i=1}^m K\left(\frac{L_{n,t} - L_{n,i}}{h}\right) \quad (11)$$

we calculate the distribution's density estimation  $\hat{f}(L_{n,t})$ , from (4) the expected bond pay-off and subsequently from (5) the bond selling price.

## 2.2. Crop Categorization by Production Areas

Now we focus on the diversity of natural conditions affecting farmer crop. By taking this circumstance into account for all farmers and analysing their yields separately, we expect a reduction of basis risk and a balance of conditions for carrying out the insurance process. Due to the spatial interconnection of farmers the effects of various factors on their crop do correlate. Confronting crops demands for natural conditions the crop needs for its prosperity with the data stored in the Credit worthy Information System (CIS) the natural conditions of the Slovak Republic according to the code of soil ecological unit, Stred'anská, Muchová and Konc (2006, p. 120) were classified according to Buday (2007, p. 28) into the following agricultural production units:

- corn production area– 1. area;
- beet production area – 2. area;
- potato production area– 3. area;
- mountain production area – 4. area.

The National Agricultural and Food Centre of the Agricultural and Food Economics Research Institute in Bratislava also operates with the above-mentioned agricultural production areas. It annually submits a publication the Green Report on the costs and revenues of agricultural products,<sup>2</sup> which contains the results of a selected set of agricultural holdings for the year in question divided by production areas. We processed the data on national hectare yields by production area and the national hectare yield of wheat for the years 1985 to 2015. Since 2016, these data for individual production areas have stopped to be published in the Green Reports, so the input data will end in 2015. We do not know the reason why the publication of these data stopped after 2015. Older data were found in the VVEP archive.

Due to the different production areas individual farmers do achieve different yields per hectare of the considered wheat crop while maintaining the general cultivation practices. Therefore, with the same premium paid, the expected claims for eventual damages vary. Thus, there is a breach of balance between premiums and the amount of insurance risk faced by all farmers who grow the same crop, in our case wheat. A same proportional reduction in the yield per hectare for farmer e.g. of the first production area does not necessarily have to lead to a claim, but at the same time there will be claims of farmers from the fourth production area. This may result into lower interest of farmers with a better soil to get an insurance and subsequently reduce the size of the premium fund. This will be followed by an increase of the probability of insurer's insolvency, reduced

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<sup>2</sup> <[http://www.vuepp.sk/04\\_naklady.htm](http://www.vuepp.sk/04_naklady.htm)>.

options for the risk transfer, an increase in insurance costs i.e. an increase of premium, which again results in a reduced interest to get this type of insurance.

Our proposal to address this drawback is to categorize farmers into the above-mentioned four agricultural production areas and offer them in each production area such an insurance coverage that would reflect the equivalent risk exposure in each of them. This step will align the claim qualification and trigger the bond of a bond emitted by the reinsurer for each production area separately.

### 3. Results

#### 3.1. Evaluation of CAT Bond for Agricultural Production Areas

For each production area, the following annual data are known hectare yields of wheat in *t/ha* and the weighted national yield per hectare used for comparison. The exponential moving average was chosen to calculate the national average and average in each production area. This choice was motivated by its cumulative properties, also by the fact, that more up-to-date data get greater importance and that used weights increase exponentially. The time series available is quite short, consisting of thirty-one members. Therefore, it is not important to try to identify the period length for convergence/divergence using a technical identifier MACD (moving average convergence-divergence). So is the reason why further on we use determination coefficients  $R^2$ . According to Kresta (2016, p. 50) the exponential moving average  $EMA(n)_t$  will be calculated as

$$EMA(n)_t = EMA(n)_{t-1} + \frac{2}{n+1}(p_t - EMA(n)_{t-1}) \quad (12)$$

where

$$EMA(n)_1 = p_1,$$

$p_t$  – average yields per hectare in *t/ha* in separate production areas.

For period length we choose  $n = 2, 3, 4, 5$  subsequently. Determination coefficients  $R^2$  for separate production areas and period lengths are listed in Table 1.

Table 1

**Determination Coefficients  $R^2$  for Period Length  $n$**

Period	1. production area	2. production area	3. production area	4. production area
$n = 2$	0,90094	0,91235	0,91376	0,90158
$n = 3$	0,76858	0,80870	0,80105	0,77391
$n = 4$	0,65193	0,72540	0,70220	0,66425
$n = 5$	0,55533	0,66152	0,61756	0,57182

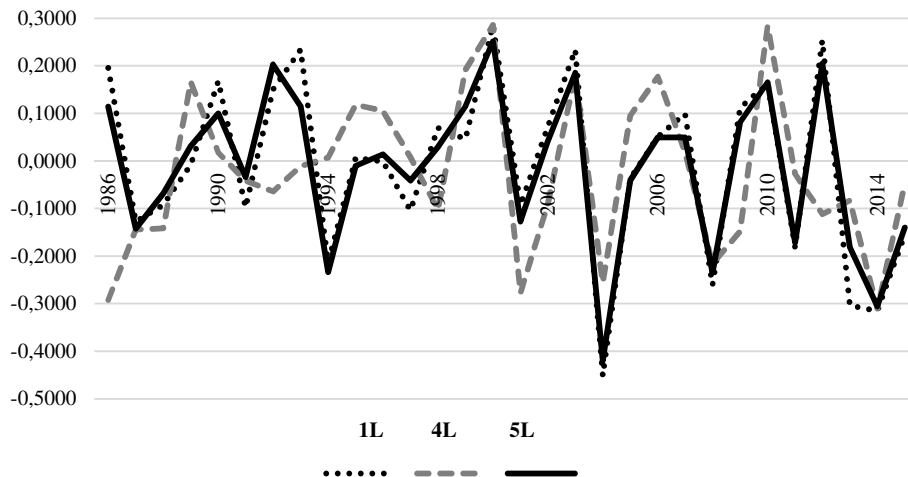
Source: Author's own work.

As seen from Table 1, the determination coefficient decreases as  $n$  increases. To maintain the credibility of smoothing the series and to maximize the period length at the same time taking into account the time series length as well (thirty-one members), it is reasonable, according to Table 1, to choose the period length  $n = 3$ . The exponential moving averages with three years period will be used to calculate the loss indexes in (7) for each production area  ${}^iL_{3,t}$ , where  $i = 1, 2, 3, 4, 5$ ; the index no. 5 represents Slovak national loss index we use for comparison, and  $t = 1986, \dots, 2015$ . Loss indexes are displayed on Figure 2; for better illustration we consider only for  $i = 1, 4, 5$ .

The time series  $\left\{ {}^iL_{3,t} \right\}_{t=1986}^{2015}$  for  $i = 1, 2, 3, 4, 5$  will be used to construct the national loss index distribution estimation and loss index distribution estimation for separate production areas. From (10) loss index definition and from (4) we see that negative index values do not reduce payments from the catastrophe bond. As seen in Figure 2 the loss index of the first production area describes the progress of the national index better than the index of the fourth production area. For example, with initial trigger value  $D = 0, 1$ , i.e. 10% in 2006 there would be no bond payment reduction for a catastrophe bond evaluated according to the national loss index in first production area. For the national loss index and the loss index of the first production area there are no claims regarding collected crop.

Figure 2

**Loss Index for First and Fourth Production Area and the Slovak National Average**



Source: Author's own work.

As seen in Figure 2 it holds for the first production area and the national production area as a whole, that

$$\delta({}^1L_{3,2006}) = \delta({}^5L_{3,2006})$$

which implies a non-existence the basis risk. But in case of the fourth production area and the national production area as whole there is

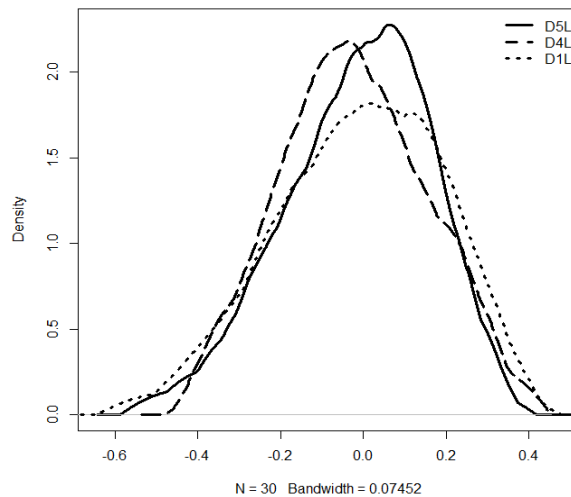
$$\delta({}^4L_{3,2006}) \neq \delta({}^5L_{3,2006})$$

so, the basis risk is present. Evaluation of CAT bond according to national data would in case of the fourth production area unfairly reflect a lower crop risk exposition. From this reason we will evaluate the CAT bond with data for each production area separately.

Let us estimate the distribution density for loss  $\hat{f}({}^iL_{3,t})$  for  $i = 1, 2, 3, 4, 5$  and  $t = 1986, \dots, 2015$  with a kernel estimation. For better illustration we show probability distributions for national loss index for the first and the fourth production area. Figure 3 was gained from the statistical Programming Language R, Páleš (2017, p. 50). For separate values of trigger  $D$  we calculate supplements to corresponding quantile in its production area category and so we get the probabilities of bond triggering.

Figure 3

**Estimate Probability Distribution of National Loss Index and the First and the Fourth Production Area**



Source: Author's own work.

They are shown in Table 2 for the first and the fourth production area and the national production area as a whole. As  $D$  decreases, the probability of bond triggering increases.

Table 2

**Probabilities of CAT Bond Trigger for Various Threshold Loss Index Values** ${}^1L_T, {}^4L_T, {}^5L_T$ 

$D$	0%	10%	20%	30%	40%	50%
$P({}^1L_T > D)$	0,5054	0,3264	0,1612	0,0520	0,0057	0,0000
$P({}^4L_T > D)$	0,4384	0,2541	0,1234	0,0362	0,0044	0,0000
$P({}^5L_T > D)$	0,5071	0,2852	0,1058	0,0204	0,0002	0,0000

Source: Author's own work.

In the following two tables we calculate according to (4) the expected catastrophe bond payments for selected parameter values for the first and the fourth production area.

Table 3

**Expected Catastrophe Bond Payments  $E({}^1V_T)$  Triggered by the Loss Index  ${}^1L_T$** 

$R_F$	$D$					
	0%	10%	20%	30%	40%	50%
<b>0,00</b>	0,49460	0,6736	0,83880	0,94800	0,99430	1,00000
<b>0,25</b>	0,62095	0,75520	0,87910	0,96100	0,99573	1,00000
<b>0,50</b>	0,74730	0,83680	0,91940	0,97400	0,99715	1,00000
<b>0,75</b>	0,87365	0,91840	0,95970	0,98700	0,99858	1,00000
<b>1,00</b>	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000

Source: Author's own work.

Table 4

**Expected Catastrophe Bond Payments  $E({}^4V_T)$  Triggered by the Loss Index  ${}^4L_T$** 

$R_F$	$D$					
	0%	10%	20%	30%	40%	50%
<b>0,00</b>	0,56160	0,74590	0,87660	0,96380	0,99560	1,00000
<b>0,25</b>	0,67120	0,80943	0,90745	0,97285	0,99670	1,00000
<b>0,50</b>	0,78080	0,87295	0,93830	0,98190	0,99780	1,00000
<b>0,75</b>	0,89040	0,93648	0,96915	0,99095	0,99890	1,00000
<b>1,00</b>	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000

Source: Author's own work.

From results comparison in Table 3 and Table 4 we see that the expected bond payments for investors do not differ substantially. This is a consequence of the fact that the loss index is being calculated from EMA of hectare yields of data from each production area.

By dividing farmers into production areas, we have not completely eliminated basis risk but we have reduced it significantly. There remains a risk of achieving different hectare yields for individual farmers in each production area, for example when the same cultivation practices are not maintained. This risk cannot be fully

eliminated anyway. However, in case of not maintaining the same cultivation practices the insurer may not acknowledge the lower yield per hectare reported to him as a claim.

We will get a different result of the expected bond payments, if for the evaluation for claim calculation we would use the data on achieved hectare yields from an arbitrary production area and EMA from the national hectare yields. For example, for the fourth – mountain – production area and EMA of the nationwide hectare yields let us denote the loss index  ${}^4L_T$  and the expected bond payments  $E({}^4V_T)$ . They are listed in Table 5.

Table 5

**Expected Catastrophe Bond Payments  $E({}^4V_T)$  Calculated with the Loss Index**

**Trigger  ${}^4L_T$**

$R_F$	$D$					
	0%	10%	20%	30%	40%	50%
<b>0,00</b>	0,05195	0,17791	0,44003	0,72908	0,90870	0,98441
<b>0,25</b>	0,28896	0,38343	0,58002	0,79681	0,93152	0,98831
<b>0,50</b>	0,52598	0,58896	0,72002	0,86454	0,95435	0,99221
<b>0,75</b>	0,76299	0,79448	0,86001	0,93227	0,97717	0,99610
<b>1,00</b>	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000

Source: Author's own work.

There is a significant difference in the expected catastrophe bond payments  $E({}^4V_T)$  in Table 4 and  $E({}^4V_T)$  in Table 5. If we used the data from each production area along with the national average hectare yield to evaluate the bond calculated by exponential moving average (EMA), then, for example, the mountain production area, as seen from its lower bond payments in Table 5, would have proportionally higher part of each monetary unit devoted to cover the losses than in the case of expected bond payments calculated from annual yields of the fourth production area and EMA of hectare yields of this production area, as stated in Table 4. By this the farmers of the fourth production area would be favoured for no reason, even though their yields are lower than in the other production areas and by this we would support the rise of the basis risk.

### 3.2. Analyses of Expected Basis Risk

By working with expected catastrophe bond's payments we further discuss the expected basis risk. We will from now on suppose that farmers in each production area reach the same hectare yields as the annual yields calculated with exponential moving average for that production area. We suppose the basis risk does not exist. Then from (10) the expected capital to cover the catastrophe losses is

$$E(\delta({}^iL_T)) = F - E({}^iV_T), \quad \text{for } i = 1, 2, 3, 4, 5$$

where  $E(\delta({}^iL_T))$  represents the expected bond payments. Let us return to Table 5 and consider the fourth production area. This area represents expected catastrophe bond payments in case of loss claim in the fourth production area, calculated with the national average. For example, for  $D = 0,2$  and  $R_F = 0,25$  there we have

$$E(\delta({}_5^4L_T)) = F - E({}_5^4V_T) = 1 - 0,58002 = 0,41998$$

If we consider the expected bond payment for the same values  $D = 0,2$  and  $R_F = 0,25$  of the fourth production area with loss claim calculated from average hectare yields of the same area as in Table 4, we have

$$E(\delta({}^4L_T)) = F - E({}^4V_T) = 1 - 0,90745 = 0,09255$$

From our assumption of non-existence of basis risk in the fourth production area the value  $E(\delta({}^4L_T)) = 0,09255$  represents capital for each monetary unit of CAT bond value used for loss coverage.

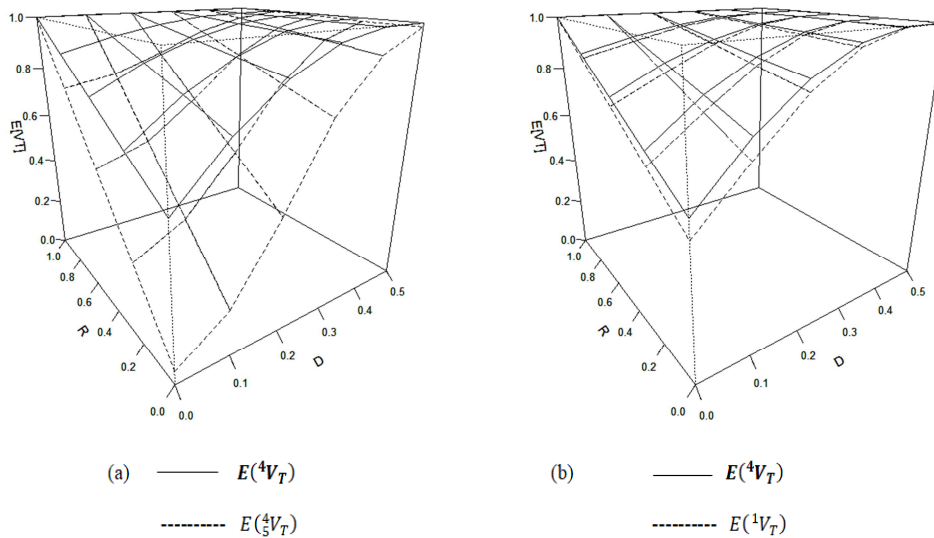
If we used the national hectare average, the capital used to cover the loss would rise to  $E(\delta({}_5^4L_T)) = 0,41998$ , so a CAT bond owner would in case of  $D = 0,2$  and  $R_F = 0$ , lose 0,32743 monetary unit for each monetary unit of the CAT bond nominal value. From bond payments as stated in Table 4 and 5 this difference rises at most to 0,56799 monetary units from 1 monetary unit of a CAT bond nominal value, which is unbearable. Such bond evaluation would always produce a basis solution.

This situation is displayed in Graph 4. On the left the expected CAT bond payments for the fourth production area calculated with the loss indexes  ${}^4L_T$  and  ${}_5^4L_T$  are displayed. On the right there is a graphic comparison of expected CAT bond payments for the first and the fourth production area calculated with the loss indexes  ${}^1L_T$  and  ${}^4L_T$ .

Let us put aside the assumption we made at the beginning of this part, so farmer yields do differ from average hectare yields of each production area. To make the basis risk for agricultural crop insurance lower and to cover agricultural crop losses it is fair to consider each production area separately and calculate the loss index from reached hectare yields data of each production area separately. A catastrophe bond evaluated in this way is justly reflecting the risk transferred to the capital market.



Figure 4  
**Expected Catastrophe Bond Payments: (A)  $E({}^4V_T)$  and  $E({}^3V_T)$ ; (B)  $E({}^4V_T)$  and  $E({}^1V_T)$  for Parameter Values  $D$  and  $R_F$**



Source: Author's own work.

To make an investor from capital market interested to invest into catastrophe bonds we must offer him an above-standard yield. These bonds are due in one year because of the vegetation cycle of each specific agricultural plant. Therefore, the bond yield must be annual and effective. When the yield offered will be for example 5% annually and effectively, by discounting the values in Table 3 and Table 4 with factor  $v = \frac{1}{1+0,05} \cong e^{-0,048790} \cong 0,95238$  we get the CAT bond purchase prices for the first and the fourth production area.

#### 4. Discussion

The paper focuses on the risk transfer of systemic risk to capital markets. Figure 1 shows the cash-flows in this process. The cash-flows considered in this manner, as in contrast to Komadel, Pinda and Sakálová (2018, p. 134), explain more precisely the insurance-securitisation process. The insurer cannot simultaneously manage a common fund created from his insurance premiums and at the same time issue or distribute CAT bonds. It must always be an independent entity, an intermediary, often referred to as a SPV. The existence of a basis risk causes a discrepancy in the identification of the loss event and the indemnity. This is

because if a certain decrease in the crop production of a farmer with a lower per hectare yield may cause a loss event to him, however, the same decrease in the harvest yield may not cause a loss event to another farmer owning a land of better quality and a higher per hectare yield. Therefore, we classified farmers according to the quality of the cultivated land into four groups, where farmers assigned to a particular class get harmonized conditions for cultivation in strict compliance to the cultivation process. From the achieved per hectare yields in each class, the CAT bond evaluation process was further developed, which transferred the systemic risk of each class to capital markets. We calculated separately for each production area with statistically verified data the exponential moving average of the per hectare yield of wheat in  $t/ha$  and subsequently the loss index, which forms the basis for the approximation of the probability distribution of losses. By processing the data of each production area separately, we achieved the expected payouts from the individual catastrophic bonds only slightly different from each other, which can clearly be seen in Figure 4b). If parameters  $R_F$  and  $D$  are set properly, the systemic risk will be eliminated to meet the investor's expectations.

The division of farmers into four agricultural production areas ultimately helped us to value CAT bonds fairly. Thus, in countries with a similar geographical spectrum of cultivated agricultural land as in Slovakia the above mentioned procedure can be applied. The tradability of CAT bonds will ultimately provide some capital to cover the loss of farmers in case a loss event occurs.

## Conclusion

The main issue of insurance in agriculture is the problem of eliminating systemic risk. Not only the insurer but also the reinsurer is endangered by systemic risk due to a limited reinsurance capacity. From the perspective of the reinsurer the systemic risk we solved using CAT bonds, by which he can transfer given risk to the capital markets on favourable terms. However, a reinsurer should only issue such CAT bonds that transfer the insurer's fairly valued insurance risk. Differences in agricultural conditions created a problem of fair insurance risk valuation. If we valued all with the same measure, basis risk would be present. We have solved this problem by dividing farmers into production areas according to the quality of the cultivated land, as this factor results indifferent growing conditions. Each farmer, according to his classification, was compensated according to a loss event in his production area. Based on these facts, the insurer was already able to formulate its reinsurance requirement to the reinsurer and according to these requirements the reinsurer evaluated and issued CAT bonds aimed for capital markets. Thus, we have eliminated the basis risk and, based on

this fact have fairly evaluated CAT bonds. The whole process is successfully completed by tradability of CAT bonds, which is conditioned by several factors. Those factors are on one hand the high yield offered taking into account the risk exposure and on the other hand the negative correlation of CAT bond yields with the yields of other securities held in investors' portfolios. In conclusion, the CAT bonds represent an attractive diversification asset.

Many foreign investors own or lease land for agricultural purposes in the Slovak Republic and grow a type of crop covered by insurance. Then, with a short position in CAT bonds, he can reinsure his harvest. However, this assumes tradability of CAT bonds on the stock market.

The above-mentioned process of insurance, reinsurance and risk transfer to the capital markets depends mainly on the creation and storage of databases of crop hectare yields. Currently, this activity is performed by the Research Institute of Agricultural and Food Economics (VÚEPP) in Bratislava. Based on this data, we were able to present a concept of hedging/reinsuring systemic risk of catastrophic proportions. After the current data is available, crop insurance can be derived from reduction of per hectare yield, in accordance with the given cultivation methods.

## References

- BARRIEU, P. – ALBERTINI, L. (2009): *The Handbook of Insurance-Linked Securities*. Chippingham, GB: Wiley. ISBN 978-0-470-74383-6.
- BUDAY, Š. (2007): *Produkčno-ekonomická kategorizácia poľnohospodárskych pôd SR*. [Habilitation Thesis.] Nitra: SPU.
- CUMMINS, J. D. – WEISS, M. A. (2009): Convergence of Insurance and Financial Markets: Hybrid and Securitized Risk-Transfer Solutions. *Journal of Risk and Insurance*, 76, No. 3, pp. 493 – 545. DOI: 10.1111/j.1539-6975.2009.01311.x.
- DOHERTY, N. A. – SCHLESINGER, H. (2001): *Insurance Contracts and Securitization*. [CESifo Working Paper, No. 559.] Munich: Center for Economic Studies and Ifo Institute (CESifo). DOI: 10.1111/1539-6975.00004.
- FUSCO, G. – MIGLIETTA, P. P. – PORRINI, D. (2018): How Drought Affects Agricultural Insurance Policies: The Case of Italy. *Journal of Sustainable Development*, 11, No. 2, pp. 1 – 13. DOI: 10.5539/jsd.v11n2p1.
- CHRASTINOVÁ, Z. (2016): Poistenie – nástroj na riešenie rizikovosti poľnohospodárskej výroby. *Ekonomika poľnohospodárstva*, 16, No. 4, pp. 1 – 16.
- KOMADEL, D. – PINDA, E. – SAKÁLOVÁ, K. (2018): Securitization in Crop Insurance with Soil Classification. *Agriculture Economics – Czech*, 64, No. 3, pp. 131 – 140. DOI: 10.17221/156/2016-AGRICECON.
- KRESTA, A. (2016): *Kvantitatívny metody investování s aplikacemi v prostředí MATLAB*. Ostrava: Ekf VŠB-TU Ostrava. ISBN 978-80-248-3898-4.
- KRUTOV, A. (2010): *Investing in Insurance Risk: Insurance-Linked Securities – A Practitioner's Perspective*. London: Nick Carver. ISBN 978-1-904-33956-4.

- LEE, J. – YU, M. (2007): Valuation of Catastrophe Reinsurance with Catastrophe Bonds. *The Journal of Insurance: Mathematics and Economics*, 41, No. 2, pp. 264 – 278. DOI: 10.1016/j.insmatheco.2006.11.003.
- LIU, Y. – KER, A. P. (2019): When Less is more: On the Use of Historical Yield Data with Application to Rating Area Crop Insurance Contracts. *Journal of Agricultural and Applied Economics*, 52, No. 2, pp. 194 – 203. DOI: 10.1017/ae.2019.40.
- PÁLEŠ, M. (2017): *Jazyk R v aktuárskych analýzach*. Bratislava: Vydavateľstvo Ekonóm. ISBN 978-80-225-4331-6.
- PINDA, E. – SMAŽÁKOVÁ, L. (2017): Securitization and CAT Bonds Pricing Methods. *International Scientific Journal*, No. 2, pp. 43 – 55.
- RAO, K. N. (2010): Index Crop Insurance. In: XU S. – ZHANG, Q. – CHEN, K. – BOYD, M.: *Proceeding of the Conference International Conference on Agriculture Risk and Food Security 2010*, 10 – 12 June 2010, Beijing, China, pp. 193 – 203.
- STREĎANSKÁ, A. – MUCHOVÁ, Z. – KONC, E. (2013): *Bonitácia a cena pôdy v pozemkových úpravách*. Nitra: Garmond Nitra. ISBN 978-80-552-1129-9.
- VEDENOV, D. – EPPERSON, J. – BARNETT, B. (2006): Designing Catastrophe Bonds to Securitise Systemic Risks in Agriculture: The Case of Georgia Cotton. *Journal of Agricultural and Resource Economics*, 31, No. 2, pp. 318 – 338. DOI: 10.22004/ag.econ.8610.
- WOODARD, J. D. – GARCIA, P. (2008): Basis Risk and Weather Hedging Effectiveness. *Agricultural Finance Review*, 68, No. 1, pp. 99 – 117. DOI: 10.1108/00214660880001221.