https://doi.org/10.17221/156/2016-AGRICECON

Securitization in crop insurance with soil classification

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Komadel D., Pinda L., Sakalova K. (2018): **Securitization in crop insurance with soil classification.** Agric. Econ – Czech, 64: 131–140.

Abstract: Securitization is an emerging alternative to transfer of insurance risk, especially in cases exceeding the capacity of reinsurance, thus extending the insurability of risks. The original subjects of securitization are the risks emerging from the aftermaths of natural disasters. The range of securitized risks has broaden rapidly over the past decade. The reason of securitization's feasibility in transfer of agricultural risks is the spatial correlation of harvests among the producers that can result in fatal loss suffered simultaneously by many producers and subsequent producer's insolvency to settle the insurance claims. The paper proposes the reduction of the insurer's risk exposure by its transfer to capital markets via catastrophe bonds. A catastrophic event is defined through the relative loss of the current national per hectare yield of the particular crop to the average yield from previous years. The number of years included in the average is subject to the minimization of the relative loss' fluctuation over the given period. The triggering probability of the catastrophe bond is calculated from the kernel estimation of the loss distribution, with the relative loss being the loss index. The general case is upgraded by the factor of soil quality. The insurer is proposed to offer the coverage according to the producers' soil. The soil classes are securitized separately, with the set of catastrophe bonds. Both cases are illustrated by the numerical example on the data set of wheat produced in the Slovak Republic over last 45 years. The outcome of the examples are the graphs of expected payoffs depending on various parameters.

Keywords: agricultural risk, catastrophe bond, insurance, risk transfer

The crop production is characterized by significant fluctuations. Its losses are mainly caused by the biological and climatic aspects. Whereas the risk arising from the former is well reducible by the producers' action, e.g. pest spraying, such options are rather limited for the latter where the loss is caused by the precipitation, temperature, and wind.

An example of a direct negative impact of precipitation is the crop damage due to the heavy rain or hail. The pressure of a thick snow layer may have similar effects. Typical cases of an adverse temperature include the late flowering because of the cold spring, the destroyed blossom due to the morning frost, and small fruits as a consequence of hot nights during the ripening period.

Despite the inability to reduce the risk of a critically low production due to the climatic factors, the producers are still able to reduce their exposure to the consequential risk of a low revenue. An insurance contract is slightly lossmaking in a good year and substantially profitable in a poor year, thus offsetting the financial impact of the production and smoothening the income dispersion. An enterprise is more stable with the insurance coverage, which contributes to capability to overcome adverse conditions.

The crop insurance has been rapidly developed over the decades. However, it suffers from the insufficient capacity to cover the catastrophe risk, i.e. the risk arising from the spatial correlation between the productions of producers, which results in the correlation of their insurance settlements. According to Wang and Zhang (2003) and Woodard et al. (2012), such feature has caused the non-existence of private market for agricultural insurance in the United States with the hail being an exception due to its non-systemic characteristics of risk. Adhikari et al. (2010) propose the insurers to provide more locally specific insurance products. Miller (2015) finds the temperature and precipitation expectation to be diversely determinative for the farmers' decisions in different latitudes.

The insurance market of the Slovak Republic has seen significant changes in 1990s within the transformation of the planned to market economy. Several insurance companies emerged after the government-run insurer had lost its monopolistic position for

https://doi.org/10.17221/156/2016-AGRICECON

underwriting insurance contracts in the country. The market has stabilized at three insurers providing producers with the coverage of their losses. The analysis of Toth and Cierna (2008) shows that 34% of Slovak farmers did not buy any insurance for their crop production in the years 2000–2006. According to Karkulin (2014), 31 to 35% of Slovak arable land is being insured every year. The Ministry of Agriculture and Rural Development of the Slovak Republic (MPRVSR) states that the aggregate premium paid within the crop insurance schemes ranged from 20 to 23 million Euro during the 2010–2014 period while the loss ratio oscillated between 30 and 60%.

Being a strategic segment of the economy, agriculture is subject to significant regulatory politics of the European Union. The member countries may establish support schemes for the harvest insurance as a contribution to safeguarding the producers' losses consequent to natural disasters, adverse climatic events, diseases or pest infestations[1]. In the case of insurance against losses resulting from natural disasters, the EU support may support up to 80% of the premium cost. Out of all the Slovak producers, only those producing wine have been supported recently[2]. The support for other crops is available via the support scheme of the MPRVSR, which reimburses up to 50% of the premium costs of the insurance against losses resulting from natural disasters[3].

Uninsurability of some risks because of the spatial correlation between the productions of producers stimulates the demand for alternative solutions for the original problem, i.e. the risk of fatal losses due to natural disasters. The MPRVSR has repeatedly recommended the establishment of a mutual fund for uninsurable risks[4]. Karkulin (2014) mentions the idea of running a mutual fund within the EU Rural Development Programmes. These funds may provide capital for the support provided to farmers suffering from losses after the natural disasters. The support of the Slovak government lacks the conception. The allocating procedure is not transparent. The producers are uncertain both about the amount of the reimbursement and the payment schedule. This is especially painful for those whose land has been flooded intentionally to prevent losses on the urban and industrial areas.

The authors propose the securitization approach to the risk management of crop producers. A government-run insurer would support the coverage of risks that are not feasible for the corporate insurance companies. In order to maintain solvency in case of an increased aggregate indemnification due to the poor harvest of the insured producers, the insurer would cede some of its risk to the capital market through the catastrophe bond. The second section describes the pay-out structure of the catastrophe bond, so as the insurer's loss from the indemnification of producers is compensated. Following the general case, the soil classification is included in the insurance policy. The third section provides the readers with the numerical example of the methods applied on the historical data of Slovak wheat production.

MATERIALS AND METHODS

A policyholder aims to receive the highest possible coverage of the risk given the premium paid. Insurance, as the process of risk pooling, is stated fairly, if each policyholder's premium corresponds with the risk exposure and if each indemnification relates strictly to the insured risk. To meet these criteria, the risk pool is usually transferred to an external administrating entity, called the insurer. If the aggregate indemnification exceeds the aggregate premium, the insurer suffers the aggregate loss. In case the transferred risk exceeds the insurer's capacity, mainly consisting from the paid premium and the return on assets, the doubts are raised about the risk of the insurer's insolvency, i.e. the inability to meet the obligations toward the policyholders. Insolvency may worsen the insurer's reputation and eventually cause the bankruptcy.

Reinsurance serves as a typical prevention from insolvency. It may be characterized as a secondary insurance in the point of the risk pool of several insurers, which is transferred to another entity, called the reinsurer. The repeated risk pool and risk transfer allows the partition of the original uninsurable risk into segments that are covered by individual entities, e.g. insurers and reinsurers. However, the extensive cooperation within the insurance market does not

[1]Article 49 of Regulation No. 1308/2013 of the European Parliament and of the Council.
[2]Annual Report of Agricultural Paying Agency for 2011 to 2014.
[3]Article 10 of Act No. 319/2011 Coll. on support of agricultural business and support of rural areas.
[4]Annual Report of the MPRVSR on agriculture and food industry for 2013 and 2014.

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allow the demanded risk to be covered. The emerging catastrophic events discourage the insurers from the risk coverage supply in particular cases. Alternative risk transfer solutions have been designed to meet the demand for the coverage of uninsurable risks. Securitization is a key risk transfer method, which connects the insurance and capital markets by the means of insurance-linked securities (ILS).

The ILS pay-out is defined to compensate the insurer, the risk cadent thus the ILS sponsor, for the aggregate loss from the insurance contracts. Hence, the ILS pays little when the aggregate indemnification is high, and vice versa, what smoothens the fluctuations of the insurer's cash flow. The main purpose of securitization is to reduce the risk of critical loss and the subsequent insolvency. The side purpose is the reverse flow of capital. Whereas reinsurance requires the insurer to pay the premium first, with the eventual reimbursement received later, securitization makes the insurer to receive payment for the ILS, with the eventual reduction of the pay-out in the case of a catastrophe. Considering the settlement time of the reinsurance contract, the reverse flow of capital allows the insurer for a swift indemnification of policyholders. Tradability of the securitized risk is, according to Barrieu and Albertini (2009), another advantage over the reinsurance. The investors can further trade the ILS at the secondary market, while the reinsurers are bound to the accepted risk in the meaning of the impossibility of trading it as a whole.

The main motivation of an investor to buy an ILS is generally a low correlation of ILS's pay-out with the pay-outs of other financial instruments. The ILS thus contributes to the diversified portfolio. According to Krutov (2010), ILS offer a type of diversification not available through the exposure to other assets. This proved to be important during the crisis of 2008, when the majority of assets, including those with a rather low correlation, devaluated. The ILS kept their returns in the typical range, because of their independency on the capital market fluctuations. Another motivation to invest in ILS is the above-average rate of return, which comes as a reward for the catastrophic risk exposure. Although originally viewed as a substitute to the reinsurance, securitization is becoming its complement (Cummins and Weiss 2008; Trottier and Lai 2016).

The catastrophe bond has been the dominant ILS over the last two decades. Contrary to the standard bond, and typically for the ILS, its pay-out depends on the realization of a catastrophic loss of its sponsor (issuer). When the catastrophe bond is sponsored (issued) by an insurer, the catastrophic event is correlated with the critical amount of indemnification. In the case of a catastrophe, the bond is triggered – its pay-out is either lowered or eliminated. The capital saved from the reduced pay-out is available for the indemnification of the policyholders. When the bond is not triggered, the investor enjoys a high return and the insurer suffers from the securitization loss, which is covered by the profit from the insurance.

The pay-out of a zero-coupon catastrophe bond with maturity at time T and face value F is defined as follows:

$$V_T = \begin{cases} A \cdot F & \text{if } L_T > D \\ F & \text{if } L_T \leq D \end{cases} \tag{1}$$

where $0 \leq A < 1$ is the parameter of reduction, D is the threshold value of the loss index L_t. If $A = 0$, the payout is eliminated. If $A = 1$, there is no payout reduction. The expected payout from (1) is given by

$$E[V_T] = F \times P(L_T \leq D) + A \times F \times P(L_T > D) \tag{2}$$

A portfolio of insurance policies issued at time t = 0 and expiring at time $t = T$ is considered here. The insurer transfers some of the risk exposure through zero-coupon catastrophe bonds defined by (1) with the respective timeline: issuance at $t = 0$ and maturity at $t = T$. The diagram in Figure 1 describes the cash flow between the parties of these contracts from the insurer's perspective. While the right side represents the risk coverage by insurance, the left side represents the risk cession to the investor. On both sides, the investor receives the payments first ($t = 0$) and pays it back later $t = T$ while investing the capital for time t under the interest rate r.

Let P be the aggregate premium and X be the aggregate indemnity in the year t. The insurer's loss from the insurance contract (left side of the diagram in Figure 1) is:

$$X - Pe^{rt} \tag{3}$$

and the loss from the securitization contract (right side of the scheme in Figure 1) is:

$$V_T - V_0e^{rT} \tag{4}$$

Where V_T and V_0 are the aggregate payout and aggregate price of all catastrophe bonds used to transfer the insurer's risk.

The insurer aims to transfer the risk to investors in order to minimize the risk of the critical total loss

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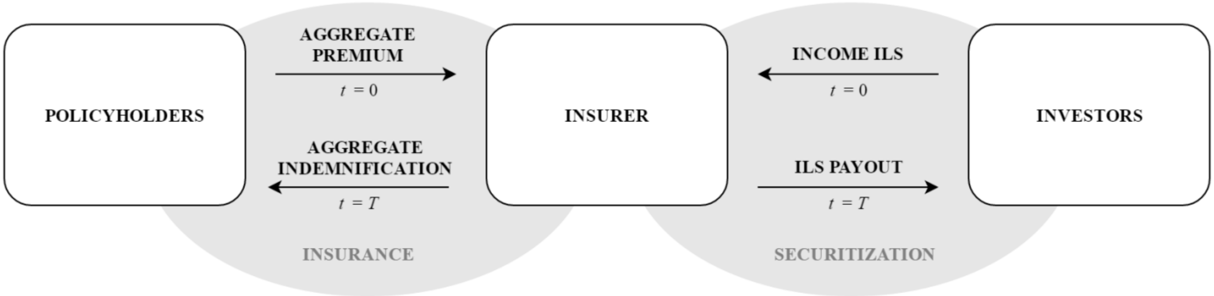

Figure 1. Cash flow among the policyholders, insurer, and investors

$X + V_T - (P + V_0)e^{rT}$, which is made by adding (3) and (4), together. This is achieved when (3) and (4) are mutually compensated. As the incomes P and V_0 are not subject to risk, the total loss is dependent on the realization of X and V_T. Their ideal correlation is achieved by X being the trigger of the bond. However, such definition is prone to the moral hazard, as the insurer is not motivated to keep the claim settlements low. While the trigger defined by a loss index is more acceptable by the investors, it exposes the insurer to the basis risk. Imperfect correlation between the index and the actual loss causes the risk of the bond not to be triggered even in case of a fatal loss. Lee and Yu (2002) have proven that both the moral hazard and the basis risk have a negative impact on the price of a catastrophe bond. The trigger design is always a trade-off between minimizing any of these to risks.

Crop securitization

A crop producer suffers from harvest fluctuations described in the introduction of this paper. The eventual low income resulting from a low yield is compensated by the insurance settlement. A country with p producers of a particular crop is considered. The amount of crop produced in the year t by a producer $i \in \{1, 2, ..., p\}$ is defined by the per hectare yield ${}^iy_t$, thus the weight of harvest over the area of land, typically measured in tons per hectare (t/ha). The national per hectare yield in the year t is given as the weighted yield of all producers:

$$y_t = \frac{1}{p}\sum_{i=1}^{p} {}^iw_t \; {}^iy_t \qquad (5)$$

where ${}^iw_t$ is a proportion of the i-th producer's land to the total land used for growing the given crop in the year t. The average national per hectare yield from n years preceding the year t (meaning the years $t = t - n, t - n + 1, ..., t - 1$) is noted as $\bar{y}_{n,t}$. Following the approach of Vedenov et al. (2006), the loss of the i-th producer in the year t is defined by the relative loss of the producer's present per hectare yield to the national average over the previous n years:

$${}^iL_{n,t} = \frac{\bar{y}_{n,t} - {}^iy_t}{\bar{y}_{n,t}} \qquad (6)$$

The insurance claim is settled in case that the loss index exceeds the threshold value D:

$${}^iL_{n,t} > D \qquad (7)$$

(6) and (7) can be rewritten as the settlement condition for the current yield

$${}^iy_t < (1 - D)\bar{y}_{n,t} \qquad (8)$$

The aggregate indemnity of all producers is a function of their present per hectare yields. While the values ${}^iy_t$ can be considered as equally distributed for $i \in \{1, 2, ..., p$, their independence is violated. The spatial correlation causes the insurer's exposure to the risk of the simultaneous claim from a number of insurers. The aggregate indemnity may cause a fatal loss for the insurer and eventually result in the insolvency. Such scenario can be considered as a catastrophic event, characterized by the fatal loss occurring with a low probability.

The authors propose this risk to be covered by the catastrophe bond with the aforementioned characteristics. Considering the growing season, a one-year bond is suggested. Since the bond is supposed to cover the risk of the insurer's fatal loss, the trigger must be correlated with ${}^iy_t$ for $i \in \{1, 2, ..., p\}$. To prevent the moral hazard and still maintain a low exposure to the basic risk, the relative loss of the national yield to its average over the previous n years is taken as a trigger:

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

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The catastrophe bond is triggered when $L_{n+1} > D$, that corresponds with

$$y_t < (1 - D)\bar{y}_{n,t} \quad (10)$$

The expected pay-out (2) of the bond covering the insurer's risk in year $t = T$ can be written as

$$E[V_T] = F \times P(L_{n,T} \leq D) + A \times F \times P(L_{n,T} > D) \quad (11)$$

where $P(L_{n,T} \leq D)$ is the triggering probability of the bond with maturity in the year $t = T$. As the parameters of the loss distribution are difficult to predict, the authors follow the step of Vedenov et al. (2006) and perform a kernel estimate of the trigger density

$$\hat{f}(L_{n,t}) = \frac{1}{mh}\sum_{i=1}^{m} K\left(\frac{L_{n,t} - L_{n,i}}{h}\right) \quad (12)$$

where $L_{n,i}$, are relative losses of the national yield (9) for years i = 1, 2, ..., m, K is a kernel function, and h is the smoothing parameter of K. The Epanechnikov kernel is applied because of its optimality analysed by Zucchini (2003), Raykar and Duraiswami (2006), and Guidoum (2015). The smoothing parameter selection is subject to the least-squares cross-validation described by Wand and Jones (1995) and Horova et al. (2012).

As the support of $L_{n,t}$ is $(-\infty\,;\,1\rangle$, the values are to be transformed before the density estimation:

$$M_{n,t} = \ln(1 - L_{n,t}) \quad (13)$$

The transformed index has an unlimited support, so its density $g(M_{n,t})$ can be estimated via (12). Density $f(L_{n,t})$ can be calculated

$$\hat{f}(L_{n,t}) = \hat{g}(M_{n,t}) \times M'_{n,t} \quad (14)$$

where $M'_{n,t}$ is the derivative of $M_{n,t}$ with respect to $L_{n,t}$. The performed transformation provides the estimate of $f(L_{n,t})$ with the support of $(-\infty; 1)$ which corresponds with the relative loss character. The probabilities from (12) are estimated from (14).

Crop securitization of classified soil

The previous case describes the fluctuations of crop production within time. The homogenous soil is considered with fluctuating other factors (e.g. adverse climate and pests). The following case focuses on the soil heterogeneity within the insured portfolio that impacts on the harvest level of producers. Because of the spatial correlation, the impact of other factors on the producers' harvest is interconnected. The authors consider this correlation to be more significant than the spatial correlation of the soil quality, which means that the yield correlation of two producers within a year is higher than the correlation of their soil quality.

Two producers, $i,j \in \{1, 2, ..., p\}$ are considered with i having a higher quality of soil. Their expected per hectare, yields in the year t are ordered as follows:

$$E[{}^{i}y_t] > E[{}^{j}y_t] \quad (15)$$

The probability of a settled claim defined by (8) is lower for the producer i which implies a lower expected indemnification at the same premium paid. This violation of the essential presumption of the premium's proportionality to risk exposure may result in a decreased demand for insurance among the producers with better soil. Possible aftermaths for the insurer include the increase in the yearly fluctuations of the aggregate indemnity due to a smaller portfolio and the increase of loss from the risk transfer (3). The compensation of the latter can be achieved through an increase of the premium that may lead to another decrease of the demand.

The authors propose the solution of this imperfection by the classification of producers according to the quality of their soil. This will allow the insurer to offer the insurance coverage with a premium better reflecting the risk exposure.

Considered are q classes of soil with decreasing quality coefficients

$$k_1 > k_2 > \cdots > k_q \quad (16)$$

where $k_l \in (0; 1\rangle$ for $l \in \{1, 2, ..., q\}$. Each of the p producers belongs to exactly one soil class. Analogically to (5), the national per hectare yield in year t from soil l, ${}_{l}y_t$, is the weighted average of the yields of producers with soil l. The average of the national per hectare yield from soil l over n years preceding the year t is given by ${}_{l}\bar{y}_{n,t}$. Analogically to (6), the loss of the i-th producer in the year t is given as the relative loss of its current yield to the n-year average of the national yields from its soil class l:

$${}^{i}_{l}L_{n,t} = \frac{{}_{l}\bar{y}_{n,t} - {}^{i}y_t}{{}_{l}\bar{y}_{n,t}} \quad (17)$$

The indemnity can be claimed when , where D is the threshold. It can be also written as

$${}^{i}y_t < (1 - D)\ {}_{l}\bar{y}_{n,t} \quad (18)$$

The statement of the aggregate indemnity being the function of yields of all producers still holds. The

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insurer's exposure to the risk of the high aggregate indemnity due to the correlated yields among the farmers holds likewise. The presumption of equally distributed yields among all producers is relaxed and the weaker presumption of equally distributed yields among the producers within the soil class is taken instead. The aggregate indemnity is thus considered to be a sum of the soil class indemnities

$$X = \sum_{l=1}^{q} {}_{l}X \qquad (19)$$

Because of the correlated yields of the producers, the insurer is exposed to the risk of simultaneous claim and thus high aggregated indemnity. To factor in the modified presumption of equal distribution, the insurer's risk is proposed to be securitized separately for each soil class. The system of q catastrophe bonds of type (1) is issued. The bond of a bond transferring the risk of high indemnity from class l is triggered by the relative loss of the actual national yield from class l to its n-year average

$${}_{l}L_{n,t} = \frac{{}_{l}\bar{y}_{n,t} - {}_{l}y_t}{{}_{l}\bar{y}_{n,t}} \qquad (20)$$

exceeding the threshold D. This is equivalent with

$${}_{l}y_t < (1 - D)\ {}_{l}\bar{y}_{n,t} \qquad (21)$$

The expected pay-out from the l-th bond is

$$E[{}_{l}V_T] = F \times P({}_{l}L_{n+1} \le D) + A \times F \times P({}_{l}L_{n+1} > D) \qquad (22)$$

The correlation of the insurer's losses from insurance and securitization of the class l is obvious from (18) and (22). ${}_{l}X$ is compensated by ${}_{l}V_T$. The correlation of the total insurer's indemnity and the total bond pay-out is given by (19) and $E[V_T] = \sum_{l=1}^{q} E[\ {}_{l}V_T]$.

The subsequent procedure for each bond is identical to the procedure performed in the previous case of the sole bond transferring the insurer's risk. The Epanechnikov kernel estimation is employed to estimate the densities of loss indices ${}_{l}L_{n,t}$ for $l \in \{1, 2, \ldots, q\}$. The respective triggering probabilities are taken to calculate the expected bond payouts.

RESULTS AND DISCUSSION

Here the authors provide the numerical example of the aforementioned methods on the data set of the national per hectare yield of wheat produced in the Slovak Republic in years 1970 to 2015[5], thus the values of y_t from (5) for $t \in \{1970, 1971, \ldots, 2015\}$. In order to calculate the loss index values (9), the value of n must be decided. It is the number of years preceding the year t that is taken into calculation of the average yield $\bar{y}_{n,t}$. This decision is made with the intent of obtaining such value of $\bar{y}_{n,t}$ that provides the best estimate of y_t for the preceding m years, thus the years $t_{N-m+1}, \ldots, t_N$, where N is the length of the data set and t_N is the last year in the data set ($N = 46$ and $t_N = 2015$ in this case). For chosen m, the n is optimized, so $L_{n,t}$ has the smallest fluctuation during $t_{N-m+1}, \ldots, t_N$. The problem can be written as follows:

$$n_m^* = \text{argmin}_{1 \le n \le N-m} \frac{1}{m} \sum_{i=t_{N-m+1}}^{t_N} |L_{n,i}| \qquad (23)$$

which respects the conditions stated by Peller and Skrovankova (2004).

To illustrate the method using a simple example, Figure 2 shows $\bar{y}_{n,t}$ for an undisclosed data set from the years $t = 1, 2, \ldots, 6$ with $m = 3$. The value n is being optimized in (23) with respect to the minimalized relative losses in the last three years (t = 4, 5, 6

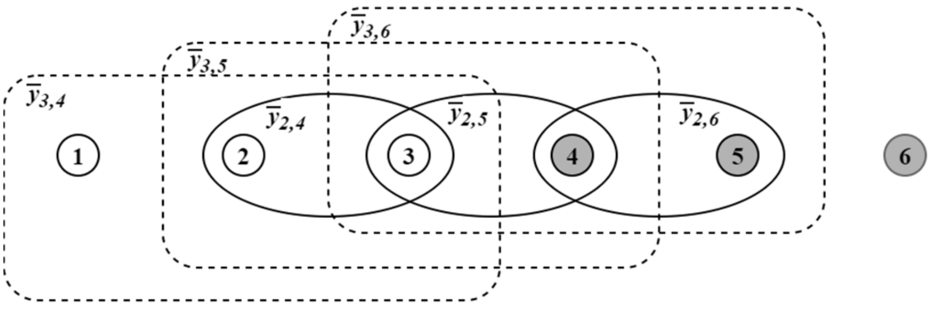

Figure 2. Average yield source data for different values of n.

[5]Data are taken from the SLOVSTAT database of the Statistical Office of the Slovak Republic. Wheat was taken as an example because it is the most grown crop in the Slovak Republic according to the SLOVSTAT.

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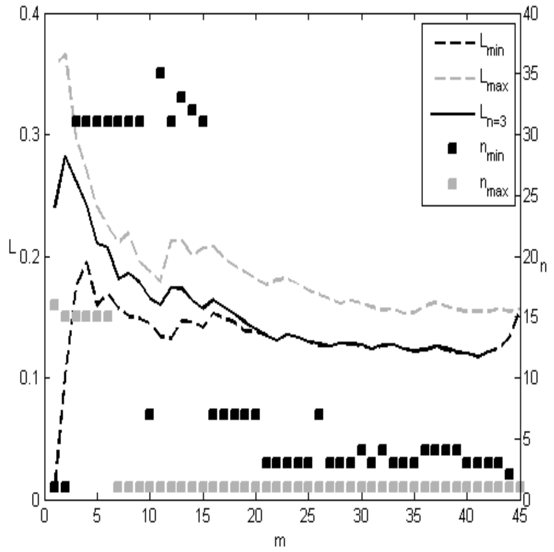

Figure 3. Minimal (dashed black line) and maximal (dashed grey line) values of the problem (23). Loss at the chosen value of n (solid black line)

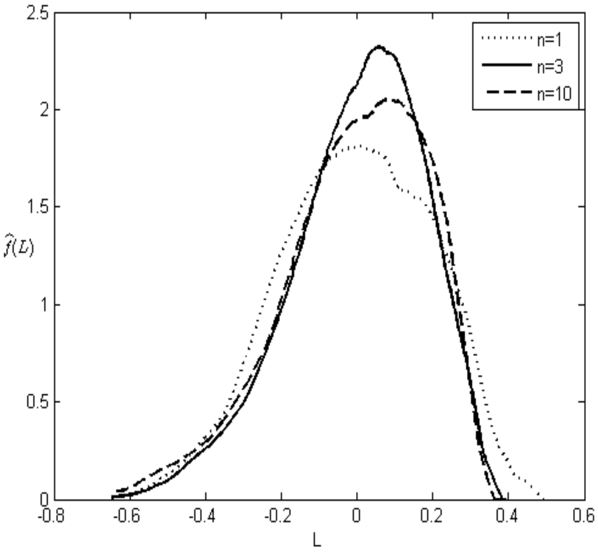

Figure 4. Estimated probability density of the loss index for various values of n

respectivelly). The n-year averages are taken from the years in rounded rectangles (n = 3) and ellipses (n = 2), respectively. Averages for n = 1 are equal to the yield values in the previous year.

Figure 3 shows the results of the minimization problem (23) for the yields of Slovak wheat with $m \in \{1, 2, \ldots, 45\}$. The black dashed curve connets the minimal values from (23) with the scale on the left vertical axis. Black squares are the minimizing values n_m^* from (23). The results can be interpreted as follows: Taking the last m years, the current national yield is accurately estimated by its average from the last n_m^* years. To make the results more illustrative, Figure 3 shows also the results for the maximizing analogy of (23). The grey dashed line connects the maximal values while the grey squares are the maximizing values of n.

As the kernel density estimation (12) requires the longest available time series, the highest values of m in (23) are of the interest. Thus, the focus is on the right side of the Figure 3. The ideal value n_m^* for $27 \leq m \leq 43$ is 3 or 4 (with one exception). On the contrary, the worst results are given by n = 1 (relative loss to the previous year). The value n_m^* = 4 is accepted as the ideal one for the further calculation. Its values are displayed with the black solid curve in Figure 3. It can be observed that its loss for such m when $n_m^* \neq 3$, is still close to the minimal values[6].

The density estimation is performed on the series that corresponds with the $m \leq N - n$. Figure 4 shows the graph of the estimated density (solid black line)[7]. The estimates for n = 1 and n = 10 are displayed for comparison. In correspondence with (23), the density for the ideal n is the one most concentrated around zero. The probabilities of $L_{3,t}$ exceeding various values of D are listed in Table 1. As an exemplar interpretation, one can say that the probability of y_{2016} (Slovak per wheat hectare yield in year 2016) being lower than the average yield from 2013–2015 (three preceding years because of n = 3) is 54%. Another conclusion from the calculated probabilities is that y_{2016} will surelly exceed 60% of the average yield from 2013–2015.

Figure 5 shows the expected pay-outs (11) for the catastrophe bond triggered by $L_{3,t}$ for various values

Table 1. Probabilities of triggering the catastrophe bond for various thresholds

D	0%	5%	10%	15%	20%	25%	30%	35%	40%
$P(L > D)$	0.5407	0.4314	0.3148	0.2084	0.1219	0.0587	0.0192	0.0023	0.0000

[6]Considering the right side of the Figure 3 because of the stated intent of large m.

[7]The value of smoothing parameter h is calculated by the Kernel Smoothing Toolbox for Matlab authored by Kolacek and Zelinka (2012).

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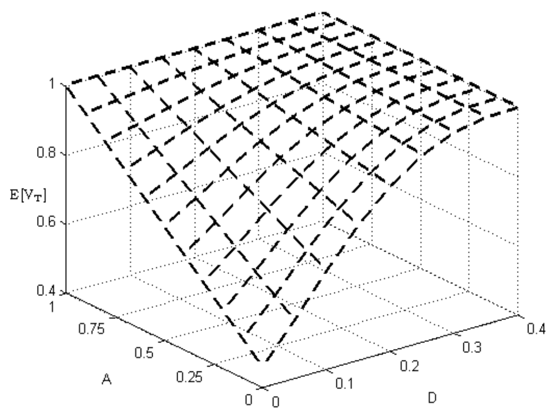

Figure 5. Expected pay-out of a catastrophe bond for various values of parameters D and A

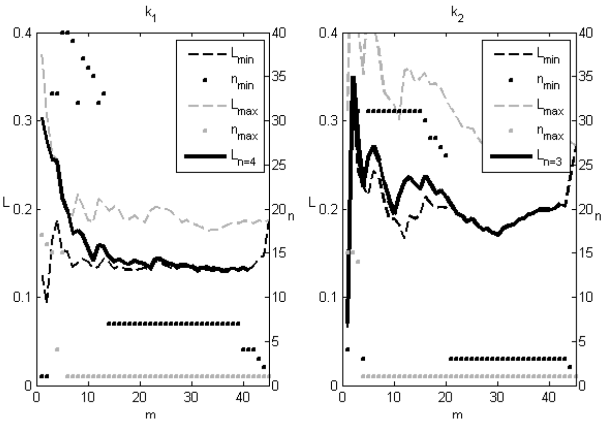

Figure 6. Minimal (dashed black line) and maximal (dashed grey line) values of the problem (23) for two soil classes. Loss at the chosen value of n (solid black line)

of the threshold D and the reduction parameter A from (1). The face value is fixed at $F = 1$. When $A = 1$ the bond surely pays 1. The same statement holds for $D = 0.4$, albeit with another reason (zero probability of triggering the bond). The decrease in A at the fixed D causes a higher reduction of F. The decrease of D causes the increase of the triggering probability. Both cases shall result in a decrease of $E[V_T]$. Figure 5 confirms this assumption.

For the sake of providing an example of the crop securitization of the classified soil, two classes, l_1 and l_2, are considered. Their coefficients are $k_1 = 1$ and $k_2 = 0.8$, respectivelly[8]. Due to the unavailability of ${}_{l}y_t$ (national per hectare yields from the respective soil classes) and ${}^{i}w_t$ (proportions of soil classes in the total arable land) from (5) for Slovak crops, the application of the aforementioned methodology is illustrated on ${}_{l}y_t$ that have been randomly generated from the real data of y_t. The historical yields of Slovak wheat production are employed again.

The values of k_1 and k_2 give

$$0.8 \times {}_{l_1}\bar{y} = {}_{l_2}\bar{y} \qquad (24)$$

Let $({}_{l_1}w\,;\ {}_{l_2}w) = (0.7; 0.3)$. In order to maintain the equality ${}_{l_1}w \times {}_{l_1}\bar{y} + {}_{l_2}w \times {}_{l_2}\bar{y} = y_t$ in every year while asymptotically sticking to (24), the annual fluctuations of ${}_{l_1}y_t$ and ${}_{l_2}y_t$ are randomized as follows: A random sample of 46 numbers (length of the yield time series) is taken from the normal distribution N(0; 0.05)[9]. The random values are added to ${}_{l_1}w \times {}_{l_1}\bar{y}$ and substracted from ${}_{l_2}\bar{y} = y_t$.

The subsequent steps are analogous to the previous example. The series $\{{}_{l_1}y_t\}_{t=1970}^{2015}$ and $\{{}_{l_2}y_t\}_{t=1970}^{2015}$ are used instead of $\{{}_{l_2}y_t\}_{t=1970}^{2015}$. The results of the minimization problem (23) for both soil classes are displayed in Figure 6, with the first class on the left and the second class on the right side. While the second class is minimized for similar values as the original case, the first class is minimal for higher values of n. Respecting the requirement of long time series for the density estimation, values $n = 4$ and $n = 3$ are taken for further calculations. Their losses dependent on m are displayed with black solid curves in Figure 6. The dashed curves and the squares represent the minimal and maximal values of the problem (23) for the respective values of m.

Figure 7 shows the density estimations of loss indices for each soil class. The ideal value of n is plotted with the solid black curve, while densities

Table 2. Probabilities of triggering the catastrophe bond for various thresholds in case of two soil classes

D	0%	5%	10%	15%	20%	25%	30%	35%	40%
$P({}_{k1}L>D)$	0.5248	0.4219	0.3207	0.2245	0.1389	0.0701	0.0254	0.0054	0.0000
$P({}_{k2}L>D)$	0.5256	0.4613	0.3894	0.3135	0.2428	0.1720	0.1148	0.0700	0.0346

[8]The parameters are supposed to correspond with the system of soil-ecological units BPEJ described by Stredanska and Buday (2006).

[9]The value of standard deviation has been chosen to obtain time series with a similar dispersion to the original time series.

https://doi.org/10.17221/156/2016-AGRICECON

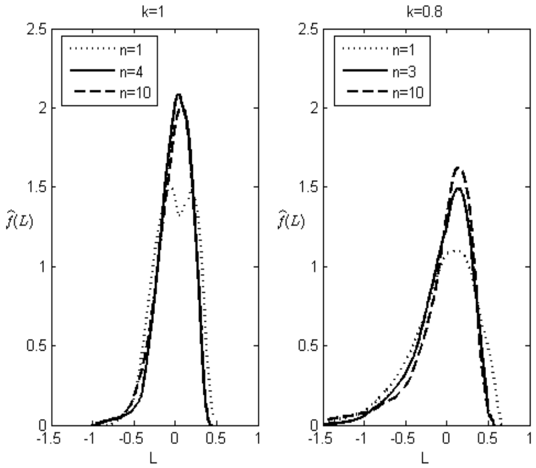

Figure 7. Estimated probability density of the loss index for various values of *n*. The first soil class on the left, the second soil class on the right

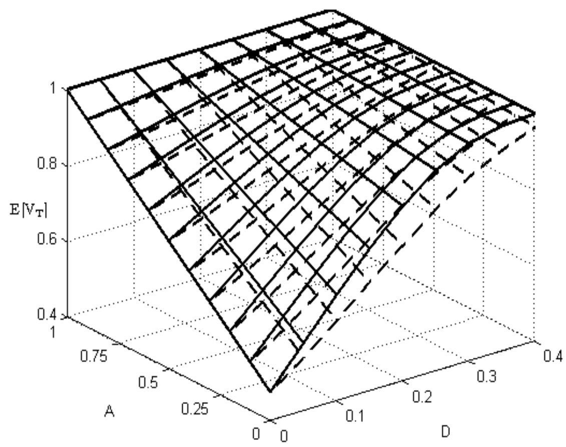

Figure 8. Expected pay-out of a catastrophe bond for various values of parameters D and A, the first soil class plotted with the solid black line and the second soil class plotted with the dashed line

for some other reference values of *n* are plotted with the dashed lines. Similar to Figure 5, the relative loss with the ideal n is concentrated around zero. The triggering probabilities of both catastrophe bonds for various thresholds are listed in Table 2. The expected pay-outs of both bonds for various values of *A* and *D* are visualized in Figure 8, with bond for the first soil class plotted with the solid line and bond for the second class plotted with the dashed line. Contrary to the first bond and the original bond from the previous example, the second bond is triggered even for the value $D = 0.4$. The expected values for both bonds are nearly identical at $D = 0$ because of the similar triggering probabilities for this threshold value. Except for $A = 1$, when none of the bonds is triggered, the expected pay-out of the second bond is lower compared to the first one.

CONCLUSION

This paper is focused on the risk faced by the insurer providing the coverage of crop producers for the case of a low yield from their production. The authors propose the insurer to transfer some of the risk to capital markets via the catastrophe bonds. Considering the previously issued catastrophe bonds, securitization is able to cover the risks that are beyond the scopes of reinsurance.

The trigger of the catastrophe bond is defined as the relative loss of the current yield to the average yield from the previous *n* years. The data set of the hectare yield of wheat produced in the Slovak Republic from 1970 to 2015 is used. The ideal value of *n* is stated to three years. The loss index $L_{3,t}$ with appropriately chosen values of *A* and *D* is able to compensate the high aggregate indemnity with the low bond pay-out.

The case of heterogeneous soil among the producers brings the inaccuracy of the insurance concept resulting in the low demand for insurance by the producers with better soil. The authors proposed to upgrade the aforementioned model with the soil classification. Each soil class is treated as a separate portfolio, including the securitization by a separate catastrophe bond. The example with two classes is provided in the paper. Because of the lack of the real data, the historical yields from each class were randomized from the national yield. The optimal values for n were set to four and three years, respectively. The relationship between the prices of two bonds is not an indicator of suitability. The bond with both low and high price can feasibly transfer the risk.

This paper attempts to provide a further scope to the feasibility of catastrophe bonds to transfer the insurer's risk in the crop insurance that has been introduced by Vedenov et al. (2006). The application falls short due to the lack of the historical data on yield from the particular soil classes. However, the emerging usage of soil-ecological units provides a solid base for a more detailed data set in future. Then, the multiple trigger approach proposed by Sun et al. (2015) shall be considered together with the soil classification to reflect the diversity of farmers' conditions.

https://doi.org/10.17221/156/2016-AGRICECON

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Received May 27, 2016
Accepted October 7, 2016
Published online December 14, 2017