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An Analysis of Black-box Optimization Problems in Reinsurance: Evolutionary-based Approaches

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Abstract

Black-box optimization problems (BBOP) are defined as those optimization problems in which the objective function does not have an algebraic expression, but it is the output of a system (usually a computer program). This paper is focussed on BBOPs that arise in the field of insurance, and more specifically in reinsurance problems. In this area, the complexity of the models and assumptions considered to define the reinsurance rules and conditions produces hard black-box optimization problems, that must be solved in order to obtain the optimal output of the reinsurance. The application of traditional optimization approaches is not possible in BBOP, so new computational paradigms must be applied to solve these problems. In this paper we show the performance of two evolutionary-based techniques (Evolutionary Programming and Particle Swarm Optimization). We provide an analysis in three BBOP in reinsurance, where the evolutionary-based approaches exhibit an excellent behaviour, finding the optimal solution within a fraction of the computational cost used by inspection or enumeration methods.

Key words: Reinsurance; Optimization Problems; Evolutionary-based algorithms.

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1 Introduction

Reinsurance is an important risk management strategy in insurance, consisting of ceding part of the insurer's risk to a reinsurer, in exchange of a reinsurance premium. It is an intelligent mechanism to reduce the insurer's risk retention, if it is able to control the reinsurance premium [24]. Mathematically, let X a random variable that stands for the loss (claim) initially set by the insurer, and $g(\cdot)$ a reinsurance function, $0 \leq g(X) \leq X$, that divides the total risk X into two parts: $g(X)$ (ceded loss part, undertaken by the reinsurer) and $X - g(X)$ or retention part (undertaken by the insurer). In general, the objective of optimal reinsurance design is to find the optimal function $g(X)$ under different risk measures, reinsurance strategies and/or premium conditions [24].

Independently of the reinsurance model and strategy considered, the final optimal solution for a reinsurance problem involves the solution of an optimization problem. In many occasions the analysis in research articles does not reach to this final stage of the problem, since specific assumptions on the model's variables and parameters need to be done. Instead, the expression of the optimization problem is described, without a final resolution of specific cases [5]. In other cases, numerical results are given, with little explanation of the optimization technique used, or just obtaining optimum values by inspection, whenever this is possible [4].

An interesting characteristic of the optimization problems in reinsurance applications is that many of them can be treated as black-box optimization problems (BBOP), since the final expression of the problem cannot be represented in the form of a simple algebraic expression, but depends on the resolution of hard models (many times integro-differential equations) with the appropriate specific parameters and simulation conditions. Evolutionary-based search algorithms have been traditionally applied to solve these problems, with excellent results [17,18].

In this paper we analyze several different optimization problems in reinsurance that can be treated as a BBOP, and solve them by using two state-of-the-art evolutionary-based approaches: Evolutionary Programming and Particle Swarm Optimization algorithms. Specifically we provide a discussion based on three optimization problems related to reinsurance contracts, that may affect to solvency of insurer and reinsurer. We show that these problems can be solved by using evolutionary approaches in an optimal way, within a fraction of the computational cost used by inspection or enumeration methods.

The rest of the paper is structured in the following way: next subsection describe the main characteristics of BBOP and the specific details of three BBOP that arise in insurance. Section 3 describes the evolutionary-based optimization approaches applied in this paper to solve the optimization problems previously described. In Section 4, numerical results are carried out, to show the good performance of evolutionary-based algorithms in the reinsurance problems discussed. Section 6 closes the paper by giving some final conclusions and remarks.

2 Black-box optimization problems in reinsurance

An optimization problem can be defined as a duple $(\mathcal{S}, f(\mathbf{x}))$, where:

- $\mathcal{S}$ is a search space, formed by feasible elements $\mathbf{x} \in \mathcal{S}$.
- $f(\mathbf{x})$ is an objective function $\mathcal{S} \rightarrow \mathbb{R}$, to be optimized (maximized or minimized).

The problem consists of obtaining $\mathbf{x}_o$ such that $f(\mathbf{x}_o) > f(\mathbf{x})$, if the problem consists of maximizing the objective function (or $f(\mathbf{x}_o) < f(\mathbf{x})$ for minimizing), with $\{\mathbf{x}_o, \mathbf{x}\} \in \mathcal{S}$.

Optimization problems can be either continuous or discrete (combinatorial optimization), depending on whether the variables involved are continuous or discrete, and can be also characterized by its structure (linear, quadratic optimization, etc.) or degree of constraints and locality (constrained global optimization, etc.). An optimization problem is called *black-box* when the objective function to be optimized does not have an algebraic expression, but it is the output of a computer program (black-box) [18]. Black-box optimization problems (BBOP) have several characteristics that make them specially difficult to be solved: first, no derivatives can be calculated on the objective function, what reduces the techniques available to solve these problems. The computation time of the objective function can also be a problem, since it can be prohibitive high (subrogate models are sometimes useful in these cases [18]). In addition, the structure of the problem cannot be exploited in the majority of BBOP cases, and sometimes, BBOPs involve some kind of noise in the objective function or their parameters, that make the optimization even more complicated [17].

BBOP appears in reinsurance field, and specifically in the analysis of the the effect of reinsurance contracts on the solvency of the two agents that participate in the contract (insurer and reinsurer) [13,19,5,4]. One of the main measures used to control solvency is the ruin probability. In fact, we analyze three different optimization BBOPs in reinsurance focussed on this measure.

2.1 Problem 1: Excess of loss reinsurance

Let us consider as first example of optimization problem the optimality problem of minimizing the joint ruin probability of insurer and reinsurer over a finite-time horizon, i.e. the probability that at least one of them gets ruined before the fixed horizon. The aim of this problem is to find the optimal split of the total premium earned by the insurer between the insurer (cedent) and the reinsurer.

This joint ruin probability depends on the statistical characteristics of the insured risk, the initial reserves of insurer and reinsurer, the time horizon and the premiums established by both companies. As we are considering here an excess of loss contract, the parameters of this specific contract (deductible and maximum) will also have an influence on this probability.

The calculus of the joint ruin probability is not easy nonetheless [3], and the problem can be treated as a BBOP after discretization of the variables involved in it. Let $\psi_{I,R}(c_R)$ be the joint ruin probability of insurer and reinsurer when it is considered that all the variables that influence this probability are fixed, except the reinsurer premium (c_R). Then the problem takes the following form:

$$\begin{aligned} \min_{c_R,} \quad & \psi_{I,R}(c_R), \\ 0 \leq c_R \leq c & \end{aligned} \tag{1}$$

where c is the total premium earned by the insurer (and paid by the policyholder) that will be split in two parts: the premium that is retained by the insurer and the premium that will receive the reinsurer (c_R).

2.2 Problem 2: Stop-loss reinsurance

In the second optimization problem considered, the function to be minimized is the absolute value of the difference between the probability of survival of the insurer and the probability of survival of the reinsurer given the insurer's survival, over a finite-time horizon. The decision variable is, as in the previous case, the reinsurer premium (c_R). Now the reinsurance contract is an stop-loss, and therefore the way of splitting the risk between the insurer and the reinsurer differs to that of the excess of loss, and the ruin and survival probabilities are different too. The parameters of the stop-loss (deductible and maximum) influence the probabilities and thus the differences to be minimized. The other factors to be taken into account are the same as in the excess of loss contract.

The calculus of this difference is a difficult one and it is not possible to find an explicit expression, so it can be solved as a BBOP. It is necessary to consider the probability of survival of the insurer with an stop-loss ($\phi_I(c_R)$), that can be obtained adapting the univariate model explained in [2]. We must also consider the probability of survival of the reinsurer given the insurer's survival. This conditional probability can be calculated as the quotient between the joint survival probability of the insurer and the reinsurer and the insurer's survival probability. The process to derive the joint survival probability, $\phi_{I,R}(c_R)$, can be found in [3] (Proposition 1) and a discretization of the claim amount distribution is also needed.

The statement of this problem is the following:

$$\begin{aligned} \min_{\substack{c_R, \\ 0 \leq c_R \leq c}} \quad & f(c_R) = \left| \phi_I(c_R) - \frac{\phi_{I,R}(c_R)}{\phi_I(c_R)} \right|, \end{aligned} \tag{2}$$

where c is the total premium earned by the insurer (and paid by the policyholder) that will be split in two parts: the premium that is retained by the insurer and the premium that will receive the reinsurer (c_R).

2.3 Problem 3: Threshold proportional reinsurance

The final problem tackled in the hardest one, and has been previously tackled in [4]. It consists of minimizing the ultimate ruin probability of the insurer in a threshold proportional reinsurance, i.e. the probability that the insurer's surplus level eventually falls below zero in case the insurer cedes a percentage of the insured risk to a reinsurer. Our aim is to find the optimal value of the parameters of this kind of reinsurance that minimize this probability.

The probability of ultimate ruin depends on the statistical characteristics of the insured risk (the distribution of the amount of each claim and the distribution of the number of claims), the initial surplus of the insurer and the premiums established by both companies. We consider that the insurer and the reinsurer use the expected value principle to calculate their premiums, and then they have to apply positive loading factors. A specific threshold proportional reinsurance can be identified by three parameters: k_1, the retention level of the insurer when its reserves are less than the threshold, k_2, the retention level of the insurer when its reserves are greater or equal than the threshold and b, the level of threshold.

Let $\psi_I(k_1, k_2, b)$ be the ultimate ruin probability of the insurer when all the variables that influence this probability are considered to be fixed except the parameters of the threshold reinsurance. Then, this problem can be expressed as follows:

$$
\begin{aligned}
&\min_{\substack{k_1, k_2, b, \\ \frac{\rho_R-\rho}{\rho_R} < k_1 \le 1, \\ \frac{\rho_R-\rho}{\rho_R} < k_2 \le 1, \\ b > 0}} \quad \psi_I(k_1, k_2, b)
\end{aligned}
$$

where ρ and ρ_R are the loading factors of the insurer and the reinsurer, respectively. If we assume certain statistical distributions for the claim amount, explicit expressions for $\psi_I(k_1, k_2, b)$ can then be found.

3 Evolutionary-based algorithms

Evolutionary-based algorithms [10,1,9,23], are robust problems' solving techniques based on natural evolution processes. They are population-based techniques which codify a set of possible solutions to the problem, and evolve it through the application of certain evolution rules. Evolutionary-based algorithms have been previously discussed in insurance applications [20–22]. In this paper we consider two different types of evolutionary-based approaches, focussed on continuous optimization problems: Evolutionary Programming and Particle Swarm Optimization.

3.1 Evolutionary algorithms: Evolutionary Programming

Among evolutionary approaches, Evolutionary Programming (EP) approaches have been successfully applied to continuous optimization problems. This algorithm is characterized by only using mutation and selection operators (no crossover is applied). Several versions of the algorithm have been proposed in the literature: The Classical Evolutionary Programming algorithm (CEP) was first described in the work by Bäck and Schwefel in [1], and analyzed later by Yao et al. in [23] and [16]. The CEP algorithm performs as follows:

(1) Generate an initial population of μ individuals (solutions). Let t be a counter for the number of generations, set it to $t = 1$. Each individual is taken as a pair of real-valued vectors $(\mathbf{x}_i, \boldsymbol{\sigma}_i)$, $\forall i \in \{1, \cdots, \mu\}$, where $\mathbf{x}_i$'s are objective variables, and $\boldsymbol{\sigma}_i$'s are standard deviations for Gaussian mutations.
(2) Evaluate the fitness value for each individual $(\mathbf{x}_i, \boldsymbol{\sigma}_i)$ (using the problem's objective function).

(3) Each parent $(\mathbf{x}_i, \boldsymbol{\sigma}_i)$, $\{i = 1, \cdots, \mu\}$ then creates a single offspring $(\mathbf{x}'_i, \boldsymbol{\sigma}'_i)$ as follows:

$$\mathbf{x'}_i = \mathbf{x}_i + \boldsymbol{\sigma}_i \cdot \mathbf{N_1(0,1)} \tag{3}$$

$$\boldsymbol{\sigma}'_i = \boldsymbol{\sigma}_i \cdot \exp(\tau' \cdot N(0,1) + \tau \cdot \mathbf{N(0,1)}) \tag{4}$$

where $N(0,1)$ denotes a normally distributed one-dimensional random number with mean zero and standard deviation one, and $\mathbf{N(0,1)}$ and $\mathbf{N_1(0,1)}$ are vectors containing random numbers of mean zero and standard deviation one, generated anew for each value of i. The parameters τ and τ' are commonly set to $(\sqrt{2\sqrt{n}})^{-1}$ and $(\sqrt{2n})^{-1}$, respectively [23], where n is the length of the individuals.

(4) If $x_i(j) > lim\_sup$ then $x_i(j) = lim\_sup$ and if $x_i(j) < lim\_inf$ then $x_i(j) = lim\_inf$.

(5) Calculate the fitness values associated with each offspring $(\mathbf{x}'_i, \boldsymbol{\sigma'}_i)$, $\forall i \in \{1, \cdots, \mu\}$.

(6) Conduct pairwise comparison over the union of parents and offspring: for each individual, p opponents are chosen uniformly at random from all the parents and offspring. For each comparison, if the individual's fitness is better than the opponent's, it receives a "win".

(7) Select the μ individuals out of the union of parents and offspring that have the most "wins" to be parents of the next generation.

(8) Stop if the halting criterion is satisfied, and if not, set $t = t + 1$ and go to Step 3.

A second version of the algorithm is the so called Fast Evolutionary Programming (FEP). The FEP was described and compared with the CEP in [23]. The FEP is similar to the CEP algorithm, but it performs a mutation following a Cauchy probability density function, instead of a Gaussian based mutation. The one-dimensional Cauchy density function centered at the origin is defined by

$$f_t(x) = \frac{1}{\pi} \frac{t}{t^2 + x^2} \tag{5}$$

where $t > 0$ is a scale parameter. See [23] for further information about this topic. Using this probability density function, we obtain the FEP algorithm by substituting step 3 of the CEP, by the following equation:

$$\mathbf{x'}_i = \mathbf{x}_i + \boldsymbol{\sigma}_i \cdot \boldsymbol{\delta} \tag{6}$$

where $\boldsymbol{\delta}$ is a Cauchy random variable vector with the scale parameter set to $t = 1$.

Finally, in [23] the *improved FEP* (IFEP) is also proposed, where the best result obtained between the Gaussian mutation and the Cauchy mutation is selected to complete the process.

3.2 Particle Swarm Optimization

Particle swarm optimization (PSO) is another population-based stochastic optimization technique developed by Eberhart and Kennedy [8], inspired by social behavior of bird flocking and fish schooling. It has also been mainly applied to solve continuous optimization problems. A PSO system is initialized with a population of random solutions, and searches for the optimal one by updating the population over several generations. PSO has no evolution operators, such as crossover and mutation as genetic algorithms do, but potential solutions instead, called *particles*, which fly through the problem search space to look for promising regions on the basis of their own experiences and those of the whole group. Thus, social information is shared, and also individuals profit from the discoveries and previous experiences of other particles in the search. The PSO is considered a global search algorithm.

Mathematically, given a swarm of N particles, each particle $i \in \{1, 2, \cdots, N\}$ is associated with a position vector $\mathbf{x}_i = (x_1^i, x_2^i, \cdots, x_K^i)$, K being the number of parameters to be optimized in the problem. Let $\mathbf{p}_i$ be the best previous position that particle i has ever found, i.e. $\mathbf{p}_i = (p_1^i, p_2^i, \cdots, p_K^i)$, and $\mathbf{g}$ be the group's best position ever found by the algorithm, i.e $\mathbf{g} = (g_1, g_2, \cdots, g_K)$. At each iteration step $k+1$, the position vector of the ith particle is updated by adding an increment vector $\Delta\mathbf{x}_i(k+1)$, called velocity $\mathbf{v}_i(k+1)$, as follows:

$$v_d^i(k+1) = v_d^i(k) + c_1 r_1 (p_d^i - x_d^i(k)) + c_2 r_2 (g_d - x_d^i(k)), \tag{7}$$

$$v_d^i(k+1) = \frac{v_d^i(k+1) \cdot V_d^{max}}{|v_d^i(k+1)|}, if |v_d^i(k+1)| > v_d^{max}, \tag{8}$$

$$x_d^i(k+1) = x_d^i(k) + v_d^i(k+1), \tag{9}$$

where c_1 and c_2 are two positive constants, r_1 and r_2 are two random parameters which are found uniformly within the interval $[0, 1]$, and v_d^{max} is a parameter that limits the velocity of the particle in the dth coordinate direction. This iterative process will continue until a stop criterion is fulfilled, this forming the basic iterative process of a standard PSO algorithm [8].

4 Numerical results

In this section we show the results obtained applying the considered evolutionary-based approaches to the three BBOPs in reinsurance. The first two problems are described by just one variable. They can be solved by an inspection algorithm that covers enough range of c_R values. The third problem is more complicated, since it involves 3 variables. A more advanced inspection algorithm can be used to solve it, DIRECT [12]. The analysis and discussion carried out consists in evaluate the quality of the solutions given by the evolutionary algorithms proposed, and also the computation time to reach this optimal solution.

4.1 Results in Problem 1

For illustration in this problem, let us assume that the number of claims in Problem 1 can be modelled as a Poisson random variable with parameter 1, and the claim amount is exponentially distributed with mean 1 monetary unit (m.u.). The initial reserves of insurer are 0.1 m.u. and the initial reserves of the reinsurer are 0.25 m.u. We consider a time horizon of two years and the premium established by the insurer (and paid by the policyholder) is 1.05 m.u. We consider in addition an excess of loss contract with deductible 0.8 m.u. and without maximum. The span of discretization used is 0.01. Figure 1 shows the function and a zoom in the zone of interest (function optimum).

The EP and PSO algorithms were applied to this problem with a reduced number of individuals (particles) in the population (swarm), 20. We run 10 experiments for each algorithm, with a maximum of 50 generations each. Table 2 shows the results obtained in this problem with the EP and PSO approaches. Note that both algorithms are able to converge fast (within very few seconds) to almost the same solution (global optimum of the function).

In Table 2, we observe that from the optimal split of the total premium earned by the insurer of 1.05 m.u. a total of 0.12 m.u. go for the reinsurer and $(1.05 - 0.12)$ m.u. for the insurer. This split gives a minimum joint ruin probability of 0.5737 (approximately). Usually, the reinsurer's premium in an excess of loss contract is calculated looking at the cost that is assumed by the reinsurer. Hence, we suggest a new method for calculating reinsurance premiums that takes into account the whole business.

4.2 Results in Problem 2

In this case, let us assume that the number of claims in Problem 2 is a Poisson random variable with parameter 1 and that the claim amount is exponentially distributed with mean 1 m.u. The initial reserves of the insurer and the reinsurer are 0 m.u. The considered horizon is two years and the premium established by the insurer (and paid by the policyholder) is 1.05 m.u. We consider an stop-loss contract with deductible 0.8 m.u. and with a maximum of 1.5 m.u. The span of discretization used is 0.01. Figure 2 shows the function and a zoom in the zone of interest (function optimum), in this case.

The EP and PSO algorithms have been also applied to this problem, with the same parameters than in the previous case. Table 3 shows the results obtained in this problem with the EP and PSO approaches. Note that in this case both algorithms converge to the same solution within a small computation time.

If the objective is to minimize the absolute value of the difference between the probability of survival of the insurer and the probability of survival of the reinsurer given the insurer's survival over a horizon of two years, the reinsurer must receive 0.14 m.u. as its premium and the insurer must retain $(1.05-0.14)$ m.u. The minimum absolute value obtained is almost zero. Thus, with this split, the probability of survival of the insurer is almost equal to the probability of survival of the reinsurer given the insurer's survival.

4.3 Results in Problem 3

This is the hardest problem we tackle in this paper, and may be solve with different assumptions. We consider two cases: first an exponential distribution with parameter 1 and second an Erlang(2,2) distribution (in both cases, the mean claim amount is one m.u.). We also assume that the number of claims follows a Poisson distribution with parameter 1, the initial surplus of the insurer is 4 m.u. and the loading factors of the insurer and the reinsurer are 0.15 and 0.25, respectively. The optimization problem is then:

$$\begin{array}{ll} \min\limits_{k_1, k_2, b,} & \psi_I(k_1, k_2, b). \\ 0.4 < k_1 \leq 1, & \\ 0.4 < k_2 \leq 1, & \\ b > 0 & \end{array}$$

If the claim amount is exponentially distributed,

$$\psi_I(k_1, k_2, b) = \begin{cases} 1 - 1.15A + Ae^{-\frac{0.521739}{k_1}}, & 4 < b, \\ \left(1 - 1.15A + Ae^{-\frac{0.130435}{k_1}b}\right) e^{\frac{0.2}{k_2}(b-4)}, & 0 < b \leq 4, \end{cases}$$

where

$$A = \frac{h}{1.15h + 0.1725(k_1 - k_2)e^{-\frac{b}{k_2}} + (0.15k_2 - h)\,e^{-\frac{0.130435}{k_1}b}},$$

with $h = 0.25(1.15k_1 - 0.15k_2)$.

If the claim amount follows an Erlang(2,2) distribution, the explicit expression of the ultimate ruin probability is more complex than in the exponential case. It can be found in [4].

The EP and PSO algorithms have been applied to this problem increasing the maximum generations allowed to 100. Table 4 shows the results obtained with the EP and PSO algorithms in this problem, including both cases of claim amount distributions considered. In this case both algorithms give also similar results, close to the global optimum of the function. The computation time remains within 10 seconds.

If the claim amount is exponentially distributed (with mean 1), the optimal strategy for the insurer is to choose a threshold level of 3.2688, not to reinsure ($k_1 = 1$) when the reserves are below this level and to reinsure with a retention level $k_2 = 0.7596477$ when the reserves are above the threshold. When the claim amount follows an Erlang(2,2) distribution, the minimum ruin probability is attained when $b = 1.98$, $k_1 = 1$ and $k_2 = 0.7615$. In this example, the exponential distribution and the Erlang(2,2) have the same mean. Then it can be concluded that the distribution of the claim amount influences the optimal strategy.

5 Discussion

Table 1 shows the exact solutions to the three problems considered using inspection algorithms (uniform inspection of c_R for the two first problems and using the DIRECT algorithm [12] in the case of the third one). It is easy to see that the solutions obtained by the evolutionary-based algorithms are very close to these exact solutions, and the computation time is a small fraction of the one employed by inspection methods. In larger problems involving more variables, the application of exact methods is many times not possible. In these cases, the application of meta-heuristics such as evolutionary algorithms is an excellent option to obtain good quality solutions with bounded computation times.

6 Concluding remarks

In this paper we have done an analysis of the application of evolutionary-based optimization techniques for black-box optimization problems (BBOP) in reinsurance. Three BBOPs have been tackled with an Evolutionary Programming approach and a Particle Swarm Optimization algorithm. The BBOPs considered are continuous optimization problems, related to reinsurance contracts, that may have an important impact in solvency of insurer and reinsurer. Two of them are one variable problems (excess of loss and stop-loss reinsurance problems), and the third one is a three variables problem related to threshold proportional reinsurance. The importance of these problems is that they allow a detailed analysis of the evolutionary-based approaches, since the solutions of the problems are known (can be obtained exactly by a full inspection algorithm in the two first problems, and bounded in the third). Thus, we have shown how the evolutionary algorithms are able to find extremely good solution to the problems within a fraction of the computation time used by inspection algorithms. Moreover, in harder BBOP, where inspection search algorithms are not applicable (higher number of variables or high constraints), evolutionary approaches are an excellent option to find good solutions in short computation times.

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List of Tables

1	Exact solutions (inspection-based algorithms).	19
2	Results in Problem 1 (excess of loss reinsurance model) using EP and PSO algorithms.	20
3	Results in Problem 2 (stop-loss reinsurance model) using EP and PSO algorithms.	21
4	Results in Problem 3 (threshold proportional reinsurance model) using EP and PSO algorithms.	22

List of Figures

1 Objective function and zoom of the excess of loss reinsurance optimization problem. 17

2 Objective function and zoom of the stop-loss reinsurance optimization problem. 18

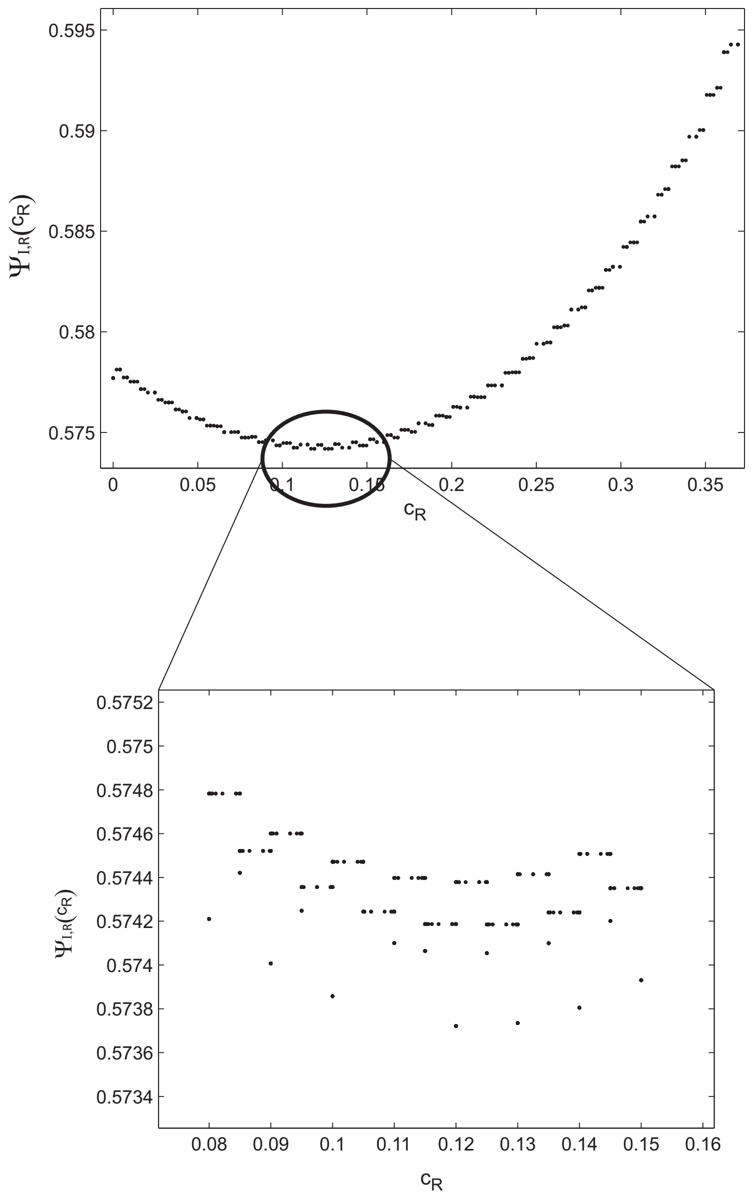

Fig. 1. Objective function and zoom of the excess of loss reinsurance optimization problem.

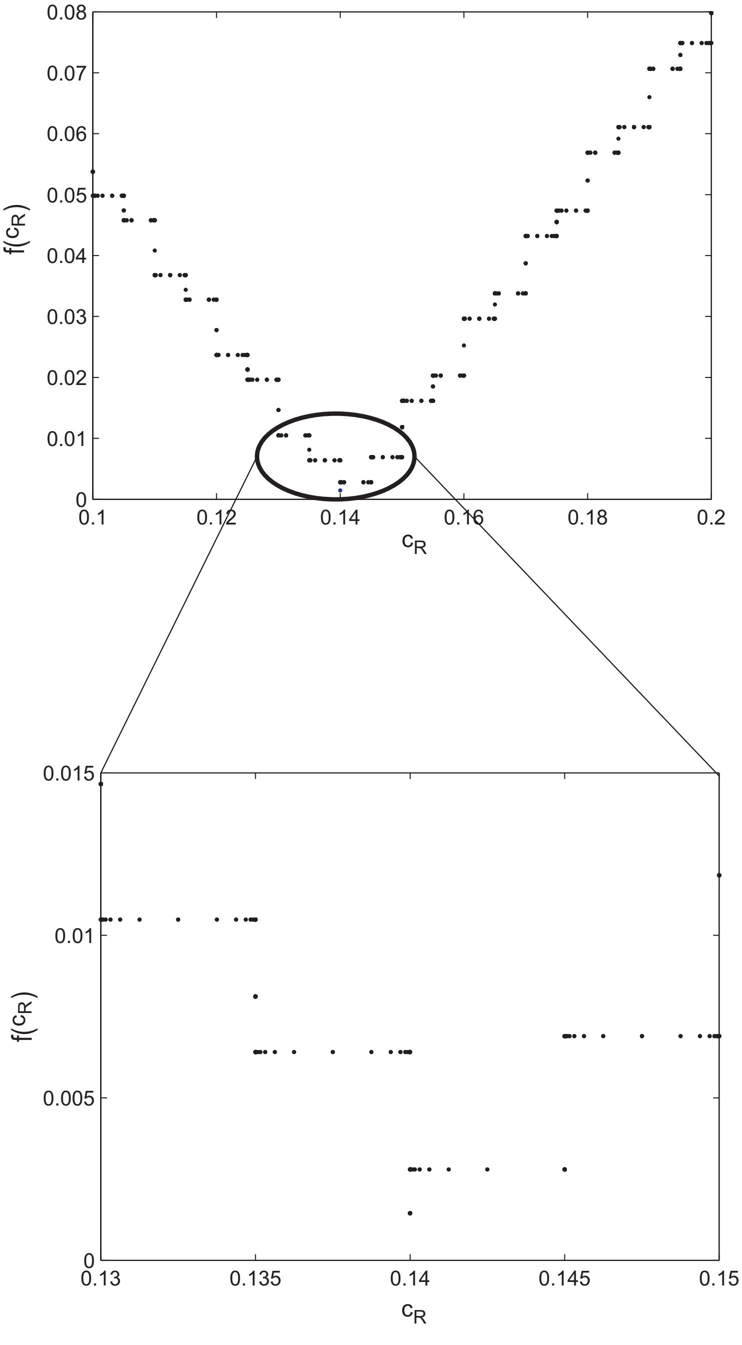

Fig. 2. Objective function and zoom of the stop-loss reinsurance optimization problem.

Table 1
Exact solutions (inspection-based algorithms).

Problem #	Optimal solution	Computation time (s)
Problem 1	$c_R = 0.1200000$; $\psi_{I,R}(c_R) = 0.573721115524965$	2100
Problem 2	$c_R = 0.1400000$; $f(c_R) = 0.001448674863134$	2840
Problem 3 (Exponential)	$k_1 = 1.0000000000$; $k_2 = 0.759647780145614$; $b = 0.759647780145614$; $\psi_I(k_1, k_2, b) = 0.498066965355012$	3700
Problem 3 (Erlang)	$k_1 = 1.000000$; $k_2 = 0.761572$; $b = 1.9871$; $\psi_I(k_1, k_2, b) = 0.415635$	3850

Table 2
Results in Problem 1 (excess of loss reinsurance model) using EP and PSO algorithms.

Algorithm	$\psi_{I,R}(c_R)$	c_R	Computation time (s)
EP	0.57372111552	0.1200013	3.5
PSO	0.5737211153	0.1200014	2.2

Table 3
Results in Problem 2 (stop-loss reinsurance model) using EP and PSO algorithms.

Algorithm	$f(c_R)$	c_R	Computation time (s)
EP	0.0014486748	0.14	2.9
PSO	0.0014486748	0.14	2.4

Table 4
Results in Problem 3 (threshold proportional reinsurance model) using EP and PSO algorithms.

Algorithm	$\psi_I(k_1, k_2, b)$	k_1	k_2	b	Computation time (s)
Exponential					
EP	0.4980669653	1.0	0.7596477801	3.2688654179	9.6
PSO	0.4980669664	1.0	0.7596477914	3.2688441178	8.5
Erlang(2,2)					
EP	0.415635	1.0	0.761572	1.9871	9.5
PSO	0.415641	1.0	0.761564	1.9866	8.5

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