Flood risk: financing for resilience using insurance adaptive schemes

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ABSTRACT. – This paper shows how insurance markets can be used for mitigating the economic consequences of climate changes, in particular for facing flood risk. Not only providing financial compensation for losses, but also for financing resilience through mitigative infrastructures. This approach is similar to one allowed by the so called resilience bonds, financial instruments whose cash flows depend on the occurrence of contractually settled (catastrophic) events and part of the economic value of the investment is devoted to finance resilience actions. Our propose is based on an adaptive design of the insurance contract, based on information collected at each checking time and the (eventual) surplus of the premium paid respect to the payments occurred for damages has to be (automatically, settled in contractual conditions) used for financing mitigative infrastructures. The cost of these infrastructures, the time to build up, the implied risk reduction, have to be assessed by an engineering expertise and even we need a legal framework into which the actuarial quantitative model can be implemented. The periodic renewals of the contract (surplus evaluation, changing in risk exposure due to the infrastructures already built,…), can be interpreted as a sort of smart contracting and in this framework the novelty of blockchain technology could be used to collect new information from various sources.

INTRODUCTION. – Since the early 1970s extreme events associated to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 years has been recorded an increase of 2% per year. This increase is reflected also on economic losses, in fact addressing the attention of the scientific and professional arenas to novel and effective methods of insurance as resilient management tools

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for risk reduction. In U.S. context the devastating impact of Hurricane Katrina in 2005 was quantify in more than 1,800 people losses within an area of 230,000 km2 of the U.S. The recovery phase investment from the federal government were quantify on 100 billion $.

These trends highlights the need to strengthen the interdisciplinary aspect towards the disaster risk management involving policy and law makers, engineers, insurance company and researchers in difference disciplines able to create tailored community resilience strategies.

Since now there have been several example on how singularly each expertise community was proposing the implementation of both mitigation and adaptive solution in ex-ante and ex-post disaster occurrence. Engineers tried to promote innovation diffusion meantime redefine more specific codes and standards to have more resistant structure. Planners were reorganizing and reassessing the land use for the development of the urban area prone to hazards.

In this context the need to have a more resilient insurance system is essential in order to be more flexible and optimizing the management of the residual risks. The example of the CAT bonds is going in this direction in fact strengthening the key role of insurance as one of the key Disaster Risk Reduction (DRR) measure with a consist effect during the recovery phase of the built environmental and the social dimensions.

Nevertheless there is evidence of a relevant decrease of the ratio of insured losses vs uninsured losses due to the increased exposure and which may be partly limited financial availability. Several authors stressed on how insurance plays a key role in food risk management like in France and UK. During the post disaster has been highlighted how insurance can substantially decrease the recovery phase in fact provide a more quick way to have repayment of the losses compared to government support.

More in specific as stated in a recent document from European Commission, for insurance in adaptation to climate change, the role of insurance should be more and more effective in the future, respect to what happened in the past. Insurance mechanisms can provide financial compensation for large disaster losses, so that those affected can recover faster. The sooner and more comprehensive the recovery, the smaller the impacts of a disaster are likely to be in the long run, which helps to make society more resilient.

Insurance companies can play a large role in assessing, communicating and signalling risk through premiums, deductibles and payments.

Stakeholders involved in the insurance sector can generate incentives or requirements for risk management, which in turn can limit the potential impacts of an extreme weather event. Another option would be to include requirements that relate to resilience in the insurance policy: if an insurance-taker does not take any measures against the risk to which he/she is exposed, the pay-out will be lower. So, the role of insurance could be considered not only for financial compensation for losses after an extreme weather event, but also providing incentives for risk reduction as, for example for flood risk, the building of mitigative infrastructures.

Some features that allow to make an insurance scheme more efficient are an interaction between public and private sectors with a commonly stated and understood objective. Governments and the insurance sector exchange data, set common objectives and divide responsibilities.

One key point for increasing resilience against extreme weather events, as floods, is the construction of mitigative infrastructures which has to be financed by the stakeholders, as public administrations. There is an important novelty in the finance-insurance market precisely regarding this kind of need, that are the so-called resilience bonds.

They provide a transfer of the insurance risk, from the insurance to the financial market, as already done by the more famous cat-bond, bonds whose payments are linked to a contractual cat-event (storm, flood, earthquake,…), but they add also a project financing of infrastructures which can mitigate the original risk. For example, focusing on flood risk, the costs of such infrastructures has to be assessed using an hydraulic engineering expertise. Then the time necessary to finish such buildings, more than one year, which is the typical duration of an insurance contract, is a constraint which implies the consideration of multi year contracts, which is the natural environment for bonds.

During this period, we need to collect data of different nature, climatic, insurance (damages), engineering,… and one instrument which seems useful to this aim is the so-called Blockchain technology, which is raising up a lot of interest for applications in a wide range of fields. The key function of its use is to collect reliable information that could be used for a dynamic updating of contracts, that is one of the main opportunity given by smart contracting, with an adequate support of law’s context in which such contracts are merged, that is one of the main issue to be developed for the full functioning of this kind of innovative business model.

Blockchain and the connected smart contracting, seem very interesting even for insurance business, in particular for the bayesian adaptive approach which is a classic issue of actuarial science, based on the updating of premium evaluation using the collection of new information of risks phenomena.

The new opportunity of collecting offered by the so-called big data even for classic insurance risks as for example, health, driving, climate and seismic events, together with the validating role of Blockchain approach, seem to be the perfect scenario for a massive use of smart contracting in insurance business.

In this paper we describe the scheme of a flood risk insurance, the bayesian adaptive design of the contract, using Blockchain to validate both new data of risk phenomenon and the effect of mitigation of the faced risk due to infrastructural works.

In the first paragraph the engineering point of view of measuring and mitigating flood risk is presented. In the second we provide an overview of the legal aspects of smart contracts in a multiperiodic scenario. In the third paragraph the bayesian adaptive design of the contract according to an actuarial approach is proposed. Then we propose some conclusions and mainly some comments of possible developing lines of this multidisciplinary research.

ASSESSMENT OF FLOOD RISK FOR CRITICAL INFRASTRUCTURAL SYSTEMS. – *FLOOD AND CRITICAL INFRASTRUCTURE.* – Since the early 1970s extreme events associate to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 has been recorded an increase of 2% a year [let see 1].

The same increased trend was also reflected on the number of disaster flood events more than 600 from the year 2007 [let see 2]. What happened in the year 2013 in the Central Europe was particularly impactful: 16.5 billion in economic losses (large-scale damage across Germany, the Czech Republic, Hungary and Poland) for 4.1 billion in insurance paid claims. The year 2013 has a record of the increasing flood damages of approximately 50% respect the period 2003-2012 and to show for first time three consecutive losses exceeding 100 billion in a 10 years period time [let see 1, 3]. These figures represent an evidence how the increase of the population in urban areas [let see 1] and the consequential increase of their complexities of both social and technological dimensions define a bottleneck within flood risk management.

In fact, the rapid growth of human concentration and urbanized areas has increased the exposure to the existing flood recurrence time making more difficult the realization of proper mitigation measures such as the availability of the land to be settled as potential flood risk zone. Among different assets which flood risk increased, exposure of Critical Infrastructures (CI) needs to be highlighted.

Critical infrastructures represent body of systems, networks and assets that are essential for the functioning of a society, public's health and/or safety and economy of a nation. CI are thus engineering and technological networks, such as energy/water supply, transport services, water supply, oil and gas supply, banking and finance, and ICT (information and communication technology) systems. All these systems are important (and thus critical) to maintain essential functions of society, and their failures can heavily seriously affect the population, economy, and national security [let see 4, 5]. Such CI systems, facing with the increase of the population in urban systems must increase the service there are providing in turn increasing both the interconnection of the CI and thus the overall vulnerability [let see 5, 6].

This is the reason that addressed the attention of policy-makers, economist, urban planners, engineers, insurance companies and scientist to find innovative Risk Management frameworks to more sustainable and more resilient approaches towards decreasing the negative effects of climate change and natural hazards [let see 7]. A new approach has thus been gradually developed, based on the concept of urban resilience, nowadays implemented within the Sendai Framework for Disaster Risk Reduction [let see 8], however a robust methodology that is based on scientific research for quantitative assessment of benefits to flood risk reduction from mitigating infrastructural solutions is still not well defined and is the next desired improvement for risk management field.

Regarding the flood impact during the last decade the disruption and damage to the urban context increased $21 billion in 2015 to US $25 billion in 2016.

It is this essential to implement proper tool, mechanism and strategy able to reduce Risk mostly in term of strengthened infrastructural resilience. It is of utmost importance how to properly quantify the risk to most effectively apply the optimal strategy for strengthening the Critical Infrastructural resilience.

The concept of Infrastructural Resilience. – Due to the complexity and interdependency of infrastructure in urban areas there is higher risk to have cascading effects in fact generating secondary effects in areas much more far from the real flooded area [let see 6, 9]. This is a key aspect to consider in order to minimize the secondary problems that are directly affecting the networks may have [let see 10].

In order to make urban areas more resilient a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed within the last Sendai Protocol developed in the 2015 based on the resilience concept [let see 11]. Sendai Protocol also foresees building the capacity to learn and thus anticipate the effect of a catastrophe, which is a substantial element for increasing resilience against natural hazards [let see 1].

For this purpose the introduction of the term resilience has important role, however the term itself is interpreted in many different ways depending on the field of science. This concept is "essential" to describe the functionality of the communities, infrastructures or any other type of systems under the effect of hazard [let see 12]. Based on the United Nations Office for Disaster Risk Reduction (UNISDR), in disaster risk management resilience is used to describe "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management". In this context the resilience is also being actualised by EU Commission to ensure appropriate planning and preparation for disaster risk management and sustainable development.

Some studies suggest that infrastructure resilience has direct connection with term of resilience proposed by Holling [12] and used in ecology. This definition is generalized as capacity of a system to absorb disturbances and to recover after a major disruption and to restart an activity on the territory. Based on this, different methods have been proposed to assess resilience and role of the infrastructural resilience within it. For example, in the work of Serre *et al.* [1] is proposed for urban/engineering networks are able to propagate flood risk the overall urban resilience is identified into 3 main capacities namely: Resistance capacity, Absorption capacity and Recovery capacity. Similarly approach for looking at resilience was proposed by Bruneau *et al.* [13] with the introduction of the "4Rs" (i.e. Robustness, Redundancy; Resourcefulness;

and Rapidity), according to which resilience of specific system is described in by qualities of the system matching these 4Rs.

Such conceptual and (semi) quantitative model approaches based on the selection of a set of proper indicators can serve as the base for development of a framework for assessing the effectiveness of specific mitigation and/or adaptation strategies.

Flood Risk and Resilience. – As mentioned urban population increase and the consequential rise of the increase complexity of the CI represent factors that amplify the level of local vulnerability [let see 14, 15]. In fact there is a direct connection of the natural hazard losses to the number of people and complex infrastructure living in areas prone to hazards.

Thus the assessment of the Risk losses is not a trivial task since both the engineering dimension as well as the social impact should be evaluated. Generally the Risk to natural disaster including flood is defined within the probability perspective in terms of occurrence time of a certain hazards, factored by the severity of its consequences [let see 16], according to the following formula:

$$Risk = Probability \times Consequence \quad \rangle \quad \rangle \quad \rangle \ (1)$$

Thus Risk represents a key instrument and criteria leading to flood zone management policy, land and infrastructural development planning [let see 17]. It is thus evident the important role of the engineering dimension to assess the potential cost/benefit in terms of decreased flood risk level once a specific (or other engineering system) is strengthened and/or newly built.

Risk formula presents also other expended description on where the probabilistic dimension of the Hazard is then related to the Exposure and Vulnerability. Both aspects are related to the intrinsic propensity of a certain asset to be at Risk. Thus, the engineering aspect to understand the effects of an hazard of a certain magnitude is essential. This general formula is reported below:

$$Risk = Hazard \times Exposure \times Vulnerability \quad \rangle \quad \rangle \quad \rangle \ (2)$$

Within the proposed Risk assessment there the need to use GIS-based system on which hazard (e.g. flood), vulnerability and assets maps are combined through the use a weighing process and normalization. This task has to be replicated for each climate-related impact [let see 18].

In this way the flood risk assessment is translated in terms of potential loss and damages costs. This is most of time impossible to be done for each infrastructure and/or asset at risk due to data scarcity. In these way insurance companies' databases are often using proxies to overcome this bottleneck.

As reported by Kaspersen and Halsnes [19] Danish Insurance Company define a damage function and unit damage costs based on flood levels for different buildings during extreme precipitation. In this case health costs (based on number of people exposed to mixed rain-sewage water) and expected costs for different rain patterns considering extremes climate event are calculated in monetary values as losses for each asset and damage costs.

Since quantitative and probabilistic approaches are not always possible to be used and converted into a monetary dimension (mostly in connection to the social dimension, the effectiveness of Risk Reduction scenarios through a Multicriteria Assessment (MCA) towards urban adaptation planning [let see 20].

Normally with adaptation strategies are beneficial for the overall resilience of certain system and thus its risk reduction. According to [21] for physical systems can be identified in 2 types of measures namely hard and soft. The first referred to (semi)permanent installation within the area of the potential flood, the second ones are those relate to natural process for example like are tackling flood in terms of erosion decrease and or increase of roughness in the flooded areas [let see 1, 22].

An overview of the legal aspects for conventional and multi-phase smart contract. – To highlight the scientific and applicative gap of a specific smart insurance contract against natural hazard, the first methodological approach, specifically the legal one, leads to an overview of the state of the art of the thematic areas of implementation of smart contracts themselves.

Our focus is to propose how a Smart Contract could act in an insurance scheme and let see Gatteschi *et al.* [23, 24] and Sayegh [25] to have an overview of the application of Blockchain approach to the insurance sector. There is no universally accepted definition of Smart Contract, due to its recent appearance on the scene and its technological complexity [see 26].

A simple definition is that of an agreement whose performance is automatic, so an algorithm for computer transactions, which comply with the terms of the contract [see 27]. Perhaps a more correct definition, even thinking about the applicative scope of the paper was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts that are written in a specific language that can be understood, translated and executed by a computer, whose clauses can produce actions without external intervention based on information received in input and processed according to predefined rules [see 28].

As regards and more closely related to the development of the paper, the most analysed state of the art, to obtain a link to the current regulatory substrate referred to in the blockchain, was clearly that of the insurance dynamics. In the insurance sector, forms of insurance have developed that use Smart Contracts. The first example is InsureETH, an UK startup, in the field of airline reimbursements/compensations. Another case is that of the pilot project of the American International Group (AIG) together with IBM and Chartered Bank who worked together for a multinational insurance coverage, preparing a blockchain insurance Smart Contract.

It is worth adding that recently AXA insurance in order to refunds following delay or cancellation of the flight, has developed an extremely interesting smart contract. The insurance called Fizzy, appears revolutionary because, as described in the AXA portal, it excludes any kind of negligence, typical instead of the traditional insurance dynamics. The smart insurance, regardless of any external event or subjective / objective liability, automatically compensates in case of flight delay.

In order to the title section, what would be the difference of a standard smart insurance contract, therefore with instant effect, compared to a multi-phase contract? One of the main differences was highlighted at the end of the section just ended, and it is quite clear that the main difference is about multiphase.

The desired multiphase implementation within the smart insurance contract is subject to the fact that, periodically, through the storage of data from external certified sources, using the blockchain technology, the contractual structure can change, such as the insurance premium, the sum of compensation or the determination of the percentage of risk. In the title of this paper we make a clear recall to this kind of insurance adaptive scheme and therefore, even if in a perspective about natural disasters, the scanned periods may be related to prolonged periods, the determination of multi-mode concerns the scanning of temporal phases in which it is possible to change and modify essential elements of the contract without the latter termination or requiring a new agreement between the parties.

The second difference concerns the method of using the blockchain technology. Picking up one of the smart contracts mentioned above in the insurance field, the blockchain is simply used in two steps: 1) validation of the insured event, such as the hours of flight delay, and 2) the payment of the sum of money [see 30]

In other words, in the very few applicative experiences that took place in the last few years, insurances first of all made use of blockchain technology as an instrument to verify the insured event. The information, using as an example the AXA contract, deriving from the airline are stored within the blockchain data flow and any event of delay beyond the allowed limit "unblocks" and acts as a check and authorization for the second step.

The one-dimensional perspective of the contract in relation to the uniqueness of the period, understood as a contractual phase, emerges clearly. The data entered and the "transformation" of these through blockchain technology into legal effects, such as compensation, are contained in a single phase, without any possibility, that extends or changes the contractual structure. Therefore, in a one-dimensional perspective, the will of the parties, the economic agreements, regardless of information, external events, blockchain technology acts exclusively as a verifying agent of the insured event, relegated to a kind, using a parallel with civil law, of contract for future effects.

On the other hand, the contract that, hopefully, should be implemented, involves a completely different dimension, that of periodic data scanning, aimed not at the termination of the contract, but at its evolution, change and adaptation.

It is essential to delineate, first, the minimal and necessary features of a multi-phase contract mentioned above, and secondly, to highlight if there are examples, even partials that can be joined from a regulatory point of view to the latter.

As regards the specific legal section, it is possible to summarize the fundamental features of the insurance contract to be implemented, in possession of the technical and legal requirements, as well as in compliance with national and supranational regulations, such as written form of the contract, multiperiod scan and related termination of the contract, initial risk, determination of the premium and possibility to use eventual surplus in risk mitigation assets.

Some of the previous point have already been clarified, then down below, it shall be pointed out the residual parts and, in general, summarized the whole framework.

First of all, in accordance with Italian and European regulations, some points, that is the essential and fundamental minimum requirements emerge clearly, and from these latter the foundations must be laid for practical implementation

In particular, the contract includes, with a view to an initial Italian implementation, the following rules: Art. 1882 et seq. Italian Civil Code, Article 8-*ter* of Legislative Decree 135.2018 converted into L 12/2019, Article 41 of Regulation (EU) n. 910/2014 of the European Parliament and of the Council, of 23 July 2014, EU Regulation 2017/1129 of the European Parliament and of the Council, of 30 June 2019, Directive 2016/97, recently implemented in Italy with Legislative Decree May 68/2018 EU Regulation of the European Commission (EU) 2017/1469 of 11 August 2017.

The second focal point relates to the mandatory written form, prescribed for all insurance contracts. in compliance with article 8-ter of Decree Law 135.2018 converted into L 12/2019 Smart contracts meet the requirement of written form subject to the IT identification of the interested parties, through a process having the requirements set by the Digital Agency for Italy (AGID) with guidelines to be adopted within ninety days from the date of entry into force of the law converting this decree. On the one hand the written form is prescribed, or rather the recognition of the validity of the smart contract in all the contracts that require the written form, on the other the guidelines of the AGID, recently diffused, say nothing against the prescriptions of the written form.

In a supranational context, in accordance with the regulations 910/2014, 2017/1129 and 2017/1469, if on the one hand the written form is prescribed, or rather the recognition of the validity, on the one hand of the information content of the insurance contract, compulsorily in writing, on the other hand as regards the smart contract, or more generally, any electronic document lacks the guidelines of individual member states.

The second profile is related to multi-periodality. This profile is allowed in the sense in which the contract is intended as a *unicum* in order not to incur the prohibition of which, in the event of a risk reduction, as originally calculated, the insurer must apply the lower premium starting from the deadline following the related communication, or, as an alternative, the express right of the contractor to withdraw from the agreement within two months of notification and with effect from the following month is reserved. In the reverse case, of an increase, therefore, of the ab initio established risk, the insured is, on the one hand obliged to give immediate notice to the insurer, and on the other, the latter has the right to withdraw from the contract with effect to date from the following month, while he cannot, continue the agreement by raising the premium or reducing the sum insured, without the express consent of the insured. The multi-period must be understood, therefore, as a multiple temporal scan within a single contractual period.

Even in the supranational panorama it seems plausible to be able to give the same conclusions as in the legislation concerning Italy, with the specification that the supranational provisions of the information content do not seem to obstruct the desired declination.

In accordance with the provisions of the Italian civil code, in compliance with the guarantees granted to the parties, it does not seem possible to change the premium without the express consensus at the time of determination of the same. Both from what can be deduced from the contrary in the provision of the Regulation of 11 August 2017 in the payment execution section, and from the provisions of the major European civil law systems, it seems that a variation, in order to the performance of the contractual, assumed as an unicum, is not feasible. Because of this, the premium, shall remain the same during the entire duration of the contract.

As regards the possible destination of a sum for mitigative infrastructures, the multi-period, and not the multi-year, therefore framing the contract as a unicum time scan, could grant the expedient of the initial fixed premium, potentially higher than a standard quantification. The allocation of part of the premium, at fixed intervals, according to the data flow, within the single time period scan, referred to in the contractual life, does not seem to suffer any prohibition. It seems therefore that this financial and environmental tool can be implemented in the sense that, since a payment by the weak party (insured) of a fixed premium, there do not seem to be any impediments to the disbursement of part of it, at certain periods and in certain circumstances, for the implementation of mitigative infrastructures.

THE ACTUARIAL MODEL: AN INSURANCE ADAPTIVE SCHEME. – In the first subsection we present the basic model to face flood risk, which implies the choice of the stakeholder, for example the public administration responsible for flood risk in a certain area, among no insurance for such risk, insurance or insurance and investment in mitigative infrastructures. In this subsection we don't consider the role of new information, collected after choice time, which can be considered into contract design, for example in terms of trend variations of the risk exposure, of the registered losses, of comparison between the premium paid and the registered losses till a certain time, and so on. This last point could be considered in order to generate potential surplus which can be invested in mitigative infrastructures.

THE BASIC MODEL: NO INSURANCE, INSURANCE OR INSURANCE AND RESILIENCE. – In this paragraph we describe the multiphase insurance adaptive scheme facing flood risk in a certain area. Let consider a random variable Y which describes the risk level in the insured area. Such random variable could describe or the rainfall registered in a fixed unit of time (hours, days, weeks,…) or the water level of one or more rivers which flow in the insured area, or some other indexes measuring the primarily source of flood risk. We assume to have historical series of the observations of this random variable, yi, with i=1,2,...n, from which we can estimate the distribution of r.v. Y, FY.

Let X the random variable which describes the random loss due to flood risk in a fixed unit of time into insured area without any mitigative infrastructures. We also assume to have historical series of the observations of this random variable, xi, with i=1,2,...n, from which we can estimate the distribution of r.v. X, FX.

In that case, applying a premium principle based on the distribution of X, we can determine a premium P[X] in the unit of time.

The insurance contractual conditions have to take count of the estimates relative to r.v. X, but it should be interesting even to estimate a regression model between X and Y, from which contractual conditions could be directly linked to the original source of risk, that can be useful (or necessary), for example, in case of losses data scarcity.

Let l be the regression function between X and Y without any mitigative infrastructures, that is X=l(Y).

From hydraulic engineering expertise we can estimate the regression function between X and Y in case of various mitigative infrastructures are built.

Let assume Ci, with i=1,2,...m, an increasing sequence of infrastructures costs, more and more efficient, such that the regression functions li, with i=1,2,...m, describe a decreasing risk exposure, given the distribution of Y.

So, let P[Xi], i=1,2,...m be the premium in the unit of time, in case of infrastructures i is built, with the same premium principle applied before, in this case to r.v. Xi =li(Y). From the previous assumption on the efficiency of mitigative infrastructures we have, P[Xi] < P[Xi+1], for each i.

If ti is the time necessary to build up infrastructures i, let assume that before the infrastructures is not finished, the risk exposure remains the original one, even if from an engineering point of view we can have a more detailed assumption in term of the evolution of risk exposure during the building time. With some further refinements to the quantitative model is possible to take count even of these aspects, but we prefer to focus on a simplified version.

The fundamental choices of the stakeholder, for example the public administration responsible of the flood risk in the area, are three:

- no insurance (and no resilience action) and payment of the random losses (in average E[X] for each unit of time);
- no insurance and resilience action through mitigative infrastructure i and payment of the random losses (in average E[X] for each unit of time) plus the constant amount ci/ti;
- insurance and no resilience action and payment of a constant amount P[X];
- insurance and resilience action through mitigative infrastructures i and payment of a constant amount P[X] + ci/ti till time ti, after that the premium P[Xi] < P[X] for each unit of time.

Indeed we have to take count that the possible infrastructures are m, and so strategies II and IV have m different scenarios.

The comparison between I and III only depends by the randomness of future losses respect to the average value estimated for the past. Roughly the same comparison of II and IV, but we have to consider that we don’t have observation of the losses relative to r.v. Xi, for each i=1, 2,… m, since the historical series cannot take count of risk mitigation given by infrastructures i. So the estimation relative to r.v. Xi, is founded only in engineering expertise.

So we focus on the crucial choice between III (in average is the same of I) and IV (in average is the same of II), for each infrastructures i, with i=1,2,… m, that is between no resilience and resilience.

Let consider the present value (PV) of the total cost, with a discount rate r, which can be fixed with many types of assumptions that we don't explore now. We have to assume a time horizon which can be + ∞ or a fixed time T. Let consider this second choice.

So the present value of the total cost in case of strategy III

$PV (III) = \sum_{j=1,2,...,T} P[X] (1+r)^{-tj}$

While the present value of the total cost in case of strategy IV with infrastructure i (ti is the time to build it), for i=1,2,...,m

$PV (IV, i) = \sum_{j=1,2,...,i} (P[X]+ ci/ti)(1+r)^{-tj} + \sum_{j=i+1, i+2,..., T} P[Xi] (1+r)^{-tj}$

So the optimal strategy is one that minimizes this total cost.

The adaptive scheme: surplus for financing mitigative infrastructures. – Given the scenario described in the previous subsection, let consider a regular time grid si, i=0, 1, 2, … k at which we reset the insurance contract in such a way.

We start without any infrastructure and we know the engineering expertise estimation on infrastructures costs and their risk reduction effects.

If P is the constant total premium paid from si to si+1, i=0, 1, 2,… k-1, and X(i, i+1) is the total loss paid in the same interval, we have two different cases.

The first P < X(i, i+1) and in that case the larger losses is covered by the insurance system.

In the second we have a surplus P – X(i, i+1) and the adaptive design of the contract could provide that part of it, a in (0,1), is given back to the insured.

These surplus are summed up and the insured, the public administration, have to choice in which kind of infrastructure invest it. In case the decision is for infrastructure i, the stakeholder has to wait to accumulate a total surplus equal to its cost, ci.

At the time, one of the regular grid introduced before, a new contract starts: the premium paid by the insured has to be estimated using information collected till that time, for a contract of further duration ti, the time necessary to build up infrastructure i. After this further duration the insurance contract will proceed with premium E[Xi], given the expected loss with infrastructure i.

Let observe that with this adaptive model the starting premium P has to be higher than the expected loss, since it has to produce the surplus necessary to finance the mitigative infrastructure. Only when the necessary surplus is raised up, then the insurance premium has to be fair compared to expected losses.

We remark that this design with a fixed premium and the distribution of the surplus is allowed by the law environment of smart contracts. For the new definition of the premium is necessary a new deal between the 2 counterparts, as stated by the same law environment.

So the optimization problem in this adaptive insurance scheme has to determine the strategy that minimizes the total cost as seen in the previous subsection. The optimal strategy has to be defined in terms of the couple P and infrastructure i. Let consider that even in this optimization problem we have to compare also the equivalent strategies no insurance or only insurance (without resilience).

The total cost for the stratey (P*, i*) is given by, let si the expected time at which the necessary surplus ci is collected.

PV (P*, i*) = Σ j =1,2,..., i P (1+r) -sj + Σ j=i +1, i +2,..., i+ti P[X] (1+r) -tj +
+ Σ j = i +ti +1, i +ti +2,..., T P[Xi] (1+r) -tj

The role of blockchain for this insurance adaptive scheme, is to certificate the information (data relative to the source of risk, to losses, to surplus, to infrastructure building) in order to allow for automatic renewals of the contract when it is not necessary a new deal between the counterparts to the contract.

Comments and further research recommendations. – This paper has presented an insurance contract facing flood risk in a multiperiodic scenario, based on an adaptive bayesian scheme, pointing out the opportunities and the criticisms by the point of view of the disciplines which are involved: actuarial, engineering, law. We disregard to detail the informatics aspects linked to the blockchain technology, leaving this issue to the specialist informatics literature. We underline that a classical actuarial approach, the bayesian adaptation due to the collection of new reliable information on the considered risk, could be inserted in a smart contract approach, with the support of blockchain technology.Since the risk is the flood one, we remark that an automatic updating scheme of the contract could concern also the infrastructures which have the role of risk mitigation and that also such component of the contract could be linked to the certification of blockchain approach.

Develops of this research could be imagined in various directions. The engineering and the actuarial approach have to dialogue in order to make their own analyses usable and useful one for the other and the legal overview has to clarify all the aspects such that the automatism provided by smart contracts in multiperiodic scenarios can be effectively conceivable in real cases.

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