XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA 10-12 Novembre 2021
ORDINE NAZIONALE DEGLI ATTUARI
CONSIGLIO NAZIONALE DEGLI ATTUARI

Climate change and hydrogeological risk: an economic resilience assessment

Emanuele Vannucci[1] (emanuele.vannucci@unipi.it), Andrea Jonathan Pagano[2], Francesco Romagnoli[2]

[1] Department of Economics and Management, University of Pisa

[2] Institute of Energy Systems and Environment, Riga Technical University

Climate change … Vannucci et al.

Motivation

- The description of possible strategies that a public administration can put in place to deal with hydrogeological risk:

- an absolute passivity (paying damages as they occur)

- a classic insurance scheme

- a resilient and innovative insurance scheme

Multidisciplinary approach:

- - the regulatory framework
- - hydraulic engineering expertise
- - actuarial schemes

The (potential) role of IT in various steps of the risk mitigation process.

Climate change … Vannucci et al.

Agenda

1) Hydrogeological risk in Europe and in Italy

2) The regulatory framework for managing risks for p.a's: Sustainable Energy and Climate Action Plan (SECAP)

3) Engineering expertise

4) A quantitative comparison among different risk management strategies

5) A numerical example

6) I.T.'s role (big data, blockchain)

7) Conclusions and further research

Climate change … Vannucci et al.

1) Hydrogeological risk in Europe (climate extreme events)

European environment agency

"Between 1980 and 2019, climate-related extremes caused economic losses totalling an estimated EUR 446 billion in the EEA member countries. … climate-related extremes are becoming more common and, without mitigating action, could result in even greater losses in the coming years. The EU adaptation strategy aims to build resilience and ensure that Europe is well prepared to manage the risks and adapt to the impacts of climate change, thus minimising economic losses and other harms."

The average annual (inflation-corrected) losses were around EUR 6.6 billion in 1980-1989, 12.3 billion in 1990-1999, 13.2 billion in 2000-2009 and 12.5 billion in 2010-2019.

Around 27 % of total losses were insured, although this also varied considerably among countries, from 1 % in Romania and Lithuania to 60 % in Belgium and Liechtenstein.

local business units

ORDINE NAZIONALE DEGLI ATTUARI

CONSIGLIO NAZIONALE DEGLI ATTUARI

XIII CONGRESSO NAZIONALE DEGLI ATTUARI

INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA

ROMA 10-12 Novembre 2021

Climate change … Vannucci et al.

1) Hydrogeological risk in Italy

«Istituto per la Protezione e la Ricerca Ambientale» (ISPRA), 2018's report

- 91% of italian municipalities is at risk (88% in 2015), more than 3 milions of families (more than 7 millions people)
- 20.808 franes in an area of 23.700 km2, 7,9% of national territory
- 600.000 business units (12,4% of the total) more than 2 milions workers
- Cultural heritage: 38.000 goods, 40.000 monuments in franes area (more than 31.000 in floodable area even in medium probability scenarios).
- 9 regions (Valle D'Aosta, Liguria, Emilia-Romagna, Toscana, Umbria, Marche, Molise, Basilicata e Calabria) 100% of municipalities are at risk

Climate change … Vannucci et al.

2) The regulatory framework for managing risks for p.a's: Sustainable Energy and Climate Action Plan (SECAP)

The regulatory framework: SECAP Covenant of Mayors for Climate and Energy (2008) is a voluntary-based initiative focused on the proactive role of local authorities for making territories (more) resilient to the impacts of climate change, produced Sustainable Energy and Climate Action Plan (SECAP) in 2015

One key point of the SECAP is Risk and Vulnerability Assessment (RVA), which is an analysis of the relevant risks and vulnerabilities, by analyzing climate hazards and assessing vulnerability (of urban sectors):

1. Municipal buildings, equipment/facilities
2. Tertiary (non-municipal) buildings, equipment/facilities
3. Residential buildings
4. Transport.

Climate change … Vannucci et al.

3) Engineering expertise

- Risk assessment and costs-benefits (in terms of mitigation respect the original level of risk) of the infrastructures that could be used for hydrogeological risk mitigation (embankments, dams, expansion tanks, ...)
- Within this process is required the risk assessment through engineering modeling including the calculation of potential losses before and after the realization of a mitigation project and the overall costs and the time required to build the resilient infrastructures.

Climate change … Vannucci et al.

4) A quantitative comparison among different risk management strategies

3 different strategies for dealing with hydrogeological risk by the public administration:

- the passive strategy, provides for the payment of damages as they occur,

- the standard insurance strategy,

- the innovative insurance resilient strategy, involves combining the standard insurance scheme with the financing of mitigating infrastructures, which will reduce risk exposure once completed.

A similar approach to one proposed in Reguero et al. (2020), but we assume a stochastic framework for the damages.

Climate change … Vannucci et al.

4.1) The model of risk exposure

- $X(h)$, i.i.d for $h = 1, 2, \dots$ the yearly random payment for hydrogeological damages,

with $\forall h$ d.f. $f(X) = f(X(h))$, and $E[X^r]$, for $r = 1, 2, \dots$

Insurance premium $P = g(f(X)) > E[X]$:

- We assume a full coverage of the damages by the insurance contract.
- $v = (1+i)^{-1}$ annual discount rate.

Obs. We may consider trends in yearly damages r.v. due to climate change process.

Climate change … Vannucci et al.

4.2) The model for risk reduction

Mitigative infrastructure with cost W and completion time n which provides that the r.v. which describes the yearly damage for following years is X_R such that

$$E[X_R]<E[X] \text{ and } \sigma[X_R]< \sigma[X]$$

from which for the insurance premium with the same function g, it holds $g(f(X_R)) = P_R < P$.

Obs. The assessment of risk reduction by engineering expertise, could be an hard task, since it cannot be evaluated using historical series of damages (the mitigative infrastructures did not exist before).

Climate change … Vannucci et al.

4.3) Passive strategy

Passive strategy, the random present value of the total payment by the public administration, fixed a generic time horizon of m years, $C_P(0,m)$, is

$$C_P(0,m) = \sum_{h=1}^{m} x_h v^h$$

with

$$E[C_P(0,m)] = E[X]\frac{1-v^m}{i}$$

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

4.4) Standard insurance strategy

- Standard insurance strategy, the present value of the total expenditure for the public administration (deterministic) is a deferred annual installment P
- $C_I(0,m) = \frac{1-v^m}{i}\ P$
- For risk aversion principle P>E[X], we have
- $E[C_P(0,m)] < C_I(0,m)$ (1)
- Obs. The passive strategy could incur in annual compensation so high as to endanger the financial solidity of the public administration, which instead, with the insurance strategy, can plan a constant yearly payment equal to P.

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

4.5) Innovative insurance resilient strategy

Resilient strategy provides that for n years it will be necessary to pay the insurance coverage P and to finance the mitigating infrastructures for which the cost W was assumed, while after completion time the annual insurance cost decreases to the level P_R.

- Q annual installment assuming that it has to be paid for the entire duration of the construction of the mitigative infrastructure, that is n years

$$W = \frac{1-v^n}{i}\ Q$$

Climate change … Vannucci et al.

4.5) Innovative insurance resilient strategy

Present value of the total expenditure (deterministic) for the first n years

$$C_R(0,n) = \frac{1-v^n}{i}\,(P + Q)$$

and the following chain of inequalities

$$E[C_P(0,n)] < C_I(0,n) < C_R(0,n)$$

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

4.6) Break-even point

Break-even point: the minimum time horizon such that the resilient strategy becomes more convenient than the others, m>n

$$C_R(0,m) = \frac{1-v^n}{i}\,(P+Q) + v^n\,\frac{1-v^{m-n}}{i}\,(PR)$$

The break-even point respect to the standard insurance strategy m_I and respect to the passive strategy m_P

- $m_I = min_{m=n+1,n+2,\dots}\ C_R(0,m) < C_I(0,m)$ (2a)
- $m_P = min_{m=n+1,n+2,\dots}\ C_R(0,m) < E[C_P(0,m)]$ (2b)

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

4.7) Break-even point with different mitigative infrastructures

A further development:

- a possible range of mitigating infrastructures, with costs and times given by pairs W(j) and n(j), in the case of the generic j-th option, j = 1, 2, …, J, from which the ex-post risk exposure distribution is described by the random variable $X_R(j)$ and the corresponding reduced premium $P_R(j)$.

- In this case the problem of optimizing the choice of the mitigating action could concern the minimum $P_R(j)$ fixed a maximum level of infrastructure cost, or the minimum in terms of break-even point provided by the different choices, that is the minimum m(j), with j ∈ 1, 2, …, J.

Climate change … Vannucci et al.

5) Numerical example: the original risk and the reduced risk premiums

- X yearly random damage lognormally distributed with parameters μ and σ.
- After mitigative infrastructures completion time, the reduced risk X_R, lognormallly distributed with parameters $\mu_R=(1-d_1)\mu$ and $\sigma_R=(1-d_2)\sigma$
- The insurance premium loading is assumed a proportion $\alpha>0$ of the volatility of the random damage even for reduced risk

$$P = E[X]+ \alpha\sigma[X]$$

$$P_R = E[X_R]+ \alpha\sigma[X_R]$$

Climate change … Vannucci et al.

5) Numerical example: standard parametrization

- μ=1, σ=2, d_1=0.1, d_2=0.1, α=0.05,
- E[X] = 20.08, σ[X] = 90.01, from which P = 24.58
- $E[X_R]$ = 12.42, $\sigma[X_R]$ = 38.09 from which P_R = 14.33
- W = 100, n = 5, i = 0.02 from which Q = 21.21 (it has to be payed for the planned n years of completion time).
- We proceed to a sensitivity analysis of the break-even points mI and mP, according to (2a) and (2b)

Climate change … Vannucci et al.

5.1) Break-even point sensitivity respect to volatility of the original risk m_I and m_P

σ	m_I	m_P
2	16	17
2.1	13	24
2,5	7	22
3	6	89

- As the volatility increases the break-even point with respect to the standard insurance strategy gets shorter
- no monotonous trend with respect to the passive strategy (the cost of the passive strategy is function only of the expected value).
- The higher is the volatility of the original risk, the less safe is the passive strategy.

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

5.2) Break-even point sensitivity respect to mitigative infrastructures cost W

W	m_I	m_P
100	16	17
110	17	29
150	21	36
200	26	45

- As expected, the break-even point gets longer as the cost of the mitigation work increases.
- It could be interesting to analyze a model such that as the cost of mitigation works increases, even their effectiveness increases, which could lead to a not-monotonous trend in the break-even point.

Climate change … Vannucci et al.

5.3) Break-even point sensitivity respect to risk reductions deriving from mitigative infrastructures measured by d_1 and d_2

- We assume that the reduction rates of the parameters that describe the original risk μ and σ, have the same value, that is $d_1 = d_2$.

$d_1 = d_2$	m_I	m_P
0.1	16	17
0.11	15	25
0.15	13	20
0.2	12	17

- The effect of shortening the break-even point with increasing effectiveness, much more pronounced for the passive strategy rather than the insurance one.

Climate change … Vannucci et al.

- **5.4) Break-even point sensitivity respect to mitigative infrastructures completion time n**

n	m_I	m_P
5	16	17
6	17	29
8	19	33
10	21	37

- Given the higher cost of the resilient strategy until the completion of the mitigation work, if this period is longer, it also entails an obvious shift in the break-even point, of roughly the same magnitude compared to the standard insurance strategy and even more pronounced compared to the passive strategy.

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

6) I.T.'s role

The various steps of the process are:

- Big data: climate phenomena and claims data collection (blockchain certification and machine learning techniques for estimation)
- Smart Contract (through blockchain's tools): the stipulation of the contract both in the insurance part and in the financing part of the mitigation work
- Certification of the timetable for the construction of the mitigation work (contractual clauses may be linked to any delays with respect to the settled timetable)
- Change in the regime of the insurance contract once the completion of the works has been certified, without the need for a new agreement on the actual exposure to risk, once this had been fixed at the signing of the contract (to be validated ex post by engineering expertise)

XIII CONGRESSO NAZIONALE DEGLI ATTUARI
INNOVAZIONE TECNOLOGICA E RISCHI SISTEMICI: L'ATTUARIO VALUTATORE GLOBALE DELL'INCERTEZZA
ROMA
10-12 Novembre 2021

Climate change … Vannucci et al.

7) Conclusions and further lines of research

- Comments:

this paper presents an innovative approach on a resilient insurance scheme for hydrogeological risk reduction by a multidisciplinary approach (legal, engineering, quantitative actuarial).

- Further research:

- analysis of the variability of the results, for example through Monte Carlo simulation, in order to highlight how the uncertainty of the cost of claims of the passive strategy may produce much more critical scenarios than other strategies, which provide a deterministic flow for managing risk

- real case data

Climate change … Vannucci et al.

Main references

- Bertoldi P. (editor) (2018). Guidebook 'How to develop a Sustainable Energy and Climate Action Plan(SECAP) Part 1 - The SECAP process, step-by-step towards low carbon and climate resilient cities by 2030, Publications Office of the European Union, Luxembourg.
- Castelli F., Galeotti M., Rabitti G. (2019). Financial instruments for mitigation of flood risks: the case of Florence, Risk Analysis, 39, 462-472.
- Pagano A.J., Romagnoli F., Vannucci E. (2019). Implementation of Blockchain Technology in Insurance Contracts Against Natural Hazards: A Methodological Multi-Disciplinary Approach, Journal of Environmental and Climate Technologies, DOI:10.2478/rtuect-2019-0091.
- Pagano A.J., Romagnoli F., Vannucci E., (2021), Climate change management: a resilience strategy for flood risk using Blockchain tools; Decisions in Economic and Finance, pp. 1-14; ISBN:1593-8883.