Financial instruments for mitigation of flood risks

The case of Florence

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About the speaker

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Some flood damages in Italy and Europe

- June 2016, Paris: 1.4 billions euros.
- December 2015, England: 6 billions pounds.
- November 2014, Tuscany: 100 millions euros.
- June 2013, Germany: 6 billion euros.
- November 2010, Veneto: 1 billion euros.

Why are needed new financial instruments?

AIM:

- to promote investment strategies to mitigate the flood risks in a region by transferring financial resources from damage covering to damage preventing.

Model assumptions

1. some preventive measures exist, whose cost is by far less than the cost of covering the damages they prevent;
2. these preventive measures require target investments (project costs), whose amount cannot be sustained by a Central Public Administration (CPA) normal economic programming;
3. the aversion to investing on preventive measures is even worsened by occurrences of catastrophes: resources previously allocated for prevention projects are diverted toward damage coverage.

Points 1) and 2) are the main motivations for issuing project options (which may be subscribed by local public administrations, LPAs) to support and finance risk prevention measures.

Points 2) and 3) are the main motivations for accompanying the project options with a second financial instrument, similar to catastrophe bonds (CAT-bonds), which can be acquired by potential investors (PIs), that:

- reinforces the remuneration of *virtuous* LPAs subsequent to certified risk reduction;
- assures the CPA for damage coverage in case of catastrophe, so that re-allocation of resources is not required.

Market incentives for environmental protection policies

Castelli and Galeotti (2013) vs. Resilience bonds (Swiss Re, 2015)

Differences among the two proposals in mechanisms and finalities:

1. the CPA is both sponsor and issuer of the financial assets;
2. two distinct instruments, instead than one, addressed to different populations of agents (LPAs and PIs), whose interaction is substantial to the effectiveness of the financial mechanism;
3. under suitable conditions, such interaction leads to an *optimal* scenario (from the CPA’s point of view), while in the resilience bonds scheme such optimal goal is never achieved.

The Central Public Administration (CPA)

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- its aim: all LPAs become virtuous = implement damage prevention projects;
- issues two different financial contracts: project options addressed to LPAs and CAT-bonds to PIs, with the aim of minimizing its overall economic risk;

The Local Public Administrations (LPAs)

- have double advantages to stipulate project options:
  1. the subscribing (*virtuous*) LPAs are fully reimbursed for the risk reducing prevention works and, moreover, receive a reward (financed by CAT-bonds emission).
  2. in case of a catastrophic event, they contribute to reconstruction works less than not-subscribing LPAs.

$\Longrightarrow$ study the dynamics that arise by activating the above financial mechanism, causing a sequence of interactions between the populations of LPAs and PIs, in an evolutionary game context.

Project Options: No catastrophe case

- What we call project option is, in fact, an incentive-deterrence pattern.
- The CPA proposes to LPAs a contract compelling the underwriter to accomplish some determined preventive works of a cost C_P.
- In case the overall hazard reduction goal in the region is attained, the subscribing (*virtuous*) LPA receives a full refunding plus a reward βC_P with $\beta > 0$.

Project Options: catastrophe case

- If, instead, a catastrophe occurs, the *non-virtuous* LPAs must fully contribute to damage costs, while the *virtuous* ones will contribute so much the less as less numerous they are, so that to encourage the subscription of contracts even when the present *virtuous* LPAs are quite few. The full contribution is μC_P, with $\mu >> 1$.

Project options: expected pay-offs

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EP_1, EP_0 the expected pay-offs of virtuous and non-virtuous LPAs.
Let x be the ratio of virtuous LPAs, $0 \leq x \leq 1$.
Let H represent the current 'average' hazard level in the region.
By a strong simplification H is assumed to be $H(x) = H_T[1 + c(1 - x)]$, where $c > 0$ and the probability of reaching the pre-fixed target will be set equal to x.
The following formulas hold:

$$EP_1 = [(1 + \beta)x - 1 - \mu x H(x)]C_P$$

$$EP_0 = -\mu H(x) C_P$$

$$\beta > 0, \ \mu >> 1$$

CAT-bonds

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The CPA offers to a population of private investors (PIs), whose number is normalized to 1, the possibility of purchasing a one-year zero coupon bond at a price P_B, with an attracting interest α in case a catastrophe does not occur.

If a catastrophe occurs, no interest is paid and the capital itself is reimbursed for a fraction so much lower as lower is the investors' number. Denote with y the normalized number of possible PIs subscribing the CAT-bonds. In this case the bond is redeemed at a value

$$V_B = \epsilon y P_B.$$

Mutually dependent incentives

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- The CPA needs to pay higher interest rates on catastrophe bonds to attract investors in higher risk regions, we can assume that α is negatively correlated with x: $\alpha = \alpha_1 - d_\alpha x$
- The CPA pays higher rewards if a higher percentage of damage costs can be covered through CAT-bonds, so that β is positively correlated with y: $\beta = \beta_0 + d_\beta y$
- It is necessary to add a risk premium π to risk-free investment with return $r > 0$, so that PIs compare the expected pay-offs of the CAT-bonds: $\pi = l + m(1 - x)$

CAT-bonds: expected pay-offs

We pose equal to 1 the unitary price of CAT-bonds, so that the works cost is also measured by CAT-bond unities.
The expected pay-off of the strategy C_1 (buying CAT-bonds) is

$$EC_1 = [(1 - H(x))\alpha - H(x)(1 - \epsilon y)]P_B.$$

For convincing an investor to buy a CAT-bond, it must happen that $EC_1 > EC_0$, where:

$$EC_0 = r + \pi,$$

with $0 \leq \epsilon \leq 1$, $r > 0$ fixed return, $\pi > 0$ risk premium.
In the following the pay-offs are normalized by the initial face value of CAT-bonds P_B and define $\rho = C_P/P_B$.

The dynamics of the system

Introducing the above financial instruments causes a dynamic interaction among CPA and two populations of LPAs and PIs, which we can represent as an continuous evolutionary game with replicating dynamics (in each population those strategies spread, at the expense of the others, whose pay-off is higher than the average one).
Then, the dynamics, taking place in $[0,1]^2$, is given by:

$$\dot{x} = x(1-x)(EP_1 - EP_0)$$
$$\dot{y} = y(1-y)(EC_1 - EC_0).$$

Such system could in general exhibit up to a maximum of 12 equilibrium points and 4 attractors, but the parameters we choose reduce these possibilities.

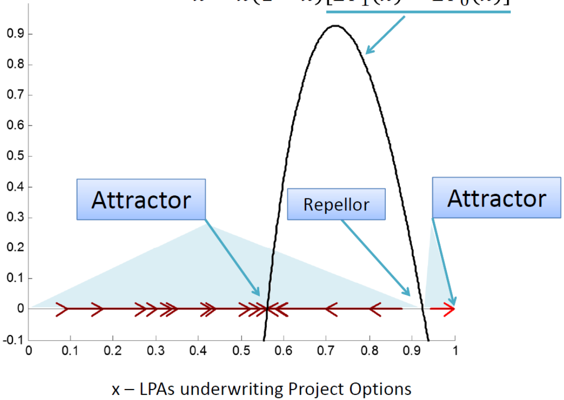
Parameter values for the case of Florence

H_T	0.005
c	3
ρ	0.33
μ	82
ϵ	0.2
α_1	0.06
d_α	0.038
β_0	0.04
d_β	0.06
$r + l$	0.02
m	0.01

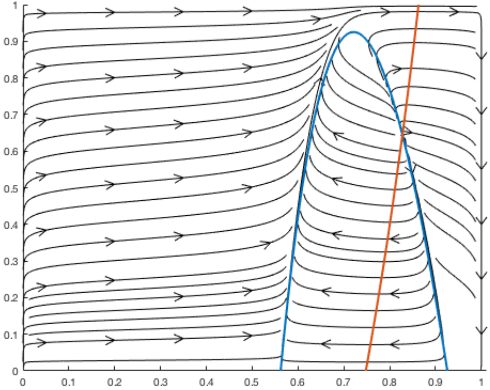
One instrument alone is not enough!

$$y = 0$$

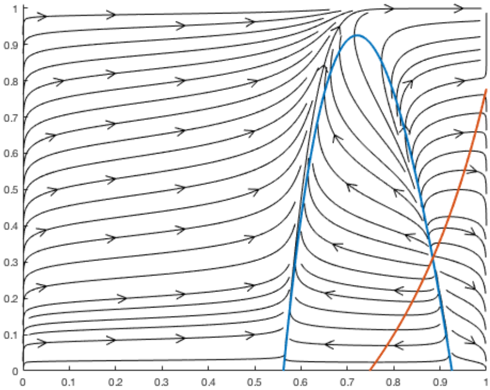
$$\dot{x} = x(1-x)[EP_1(x) - EP_0(x)]$$



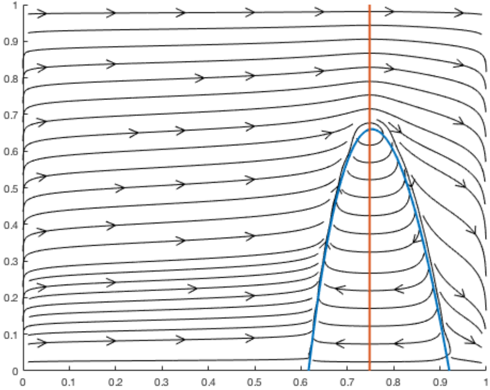
CAT-bonds allow to bypass the block: optimality



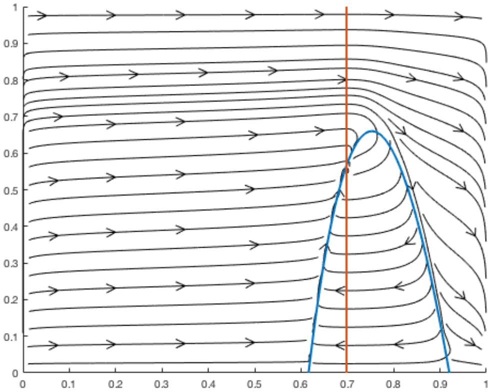
Two attractors: possible permanent indebtment



Two attractors, one cycle: subcritical Hopf bif.



The role of the parameter m



Conclusions and comments

- The parameter ϵ, decided by CPA, is the *critical* parameter: it can't be too high (increase CPA's debt) and can't be too low (encourage the PIs to buy CAT-bonds and avoid $sub-optimal$ cases 3,4).
- When ϵ is low, optimal scenarios can be directly produced.
- When ϵ is high, the CPA's goal can be achieved at two conditions:
  - the number of *virtuous* LPAs at the beginning of the emission must be sufficiently high;
  - the quote of emitted CAT-bonds must be carefully monitored by the CPA: it must be sufficiently high as to convince *non-virtuous* LPAs to become *virtuous*, and at the same time it must be sufficiently low in order to prevent the LPAs from remaining *virtuous* only if an excessive bonus, financed by CAT-bonds, is awarded.

Thank you very much for your attention!

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