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From earthquake measures to insurance premium: a method to value the seismic risk with application to the case of Italy

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(IVASS)

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Paper's aim

Estimate the probability and the damage of earthquakes
and the pure premium of a general insurance policy for Italian residential buildings
using available seismic data

Presentation summary

- Italy’s seismic risk
- The under-insurance of natural risks
- The INGV approach to seismic risk measurement
- An insurance-based approach
- Assessing the insurance premium for seismic risk covering the Italian housing stock
- Final remarks on the available policy options

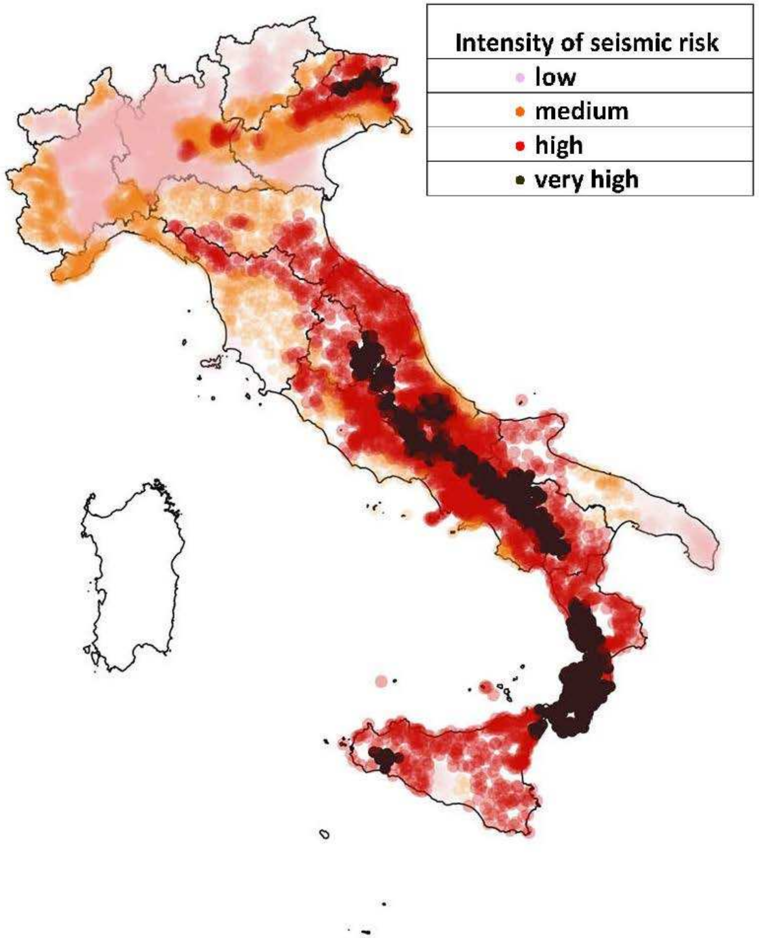
Italy's seismic risk

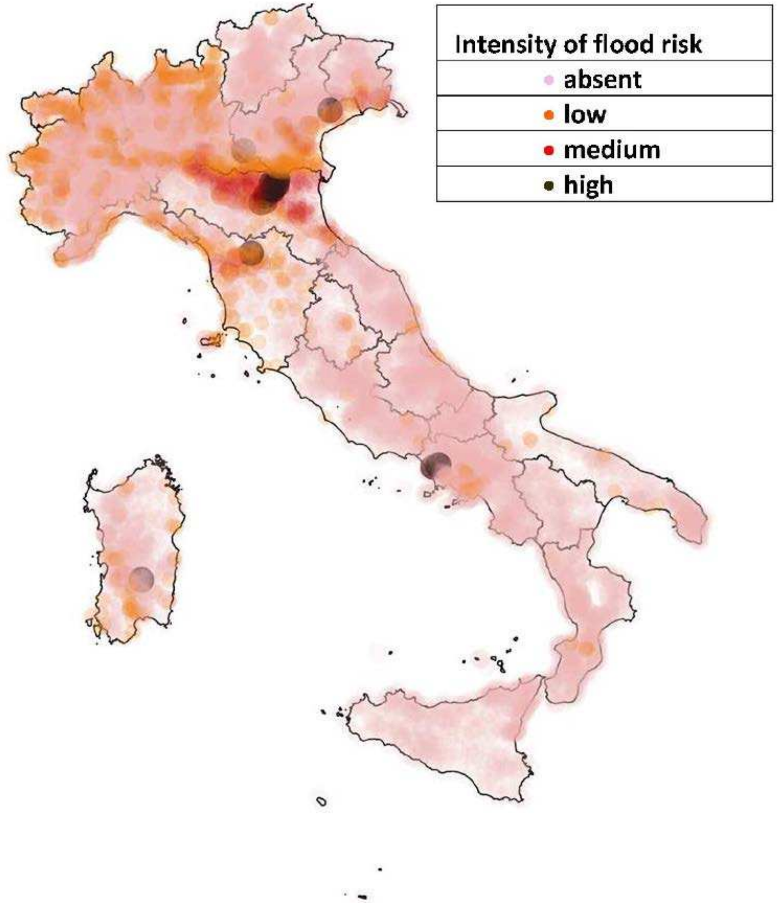
- Most dangerous European country, 8th at the world level
- Risk level: 3% of the Italian GDP (50 bil €) for a 250-year event (MCS ≥ 6.7 on space-average over all Italy, but MCS>=8.7 for 5% of Italy's surface)
- 40% of the Italian population exposed to high-very high seismic risk
- Flood risk comparatively less dangerous: 5.3% of the population exposed to medium-to-high risk (damages amounting to 0.84% of Italian GDP for a 200-year event)
- The two risks are spatially uncorrelated

Earthquake vs flood 1/2

Seismic risk level[b]	Flood risk level[a]									
	absent		low		medium		high		**Total**	
	Municipalities[c] *(units, %)*									
low	2,536	31.8%	521	6.5%	52	0.7%	2	0.0%	**3,111**	**39.0%**
medium	1,493	18.7%	350	4.4%	141	1.8%	11	0.1%	**1,995**	**25.0%**
high	2,054	25.7%	83	1.0%	32	0.4%	2	0.0%	**2,171**	**27.2%**
very high	688	8.6%	13	0.2%	0	0.0%	0	0.0%	**701**	**8.8%**
Total	**6,771**	**84.9%**	**967**	**12.1%**	**225**	**2.8%**	**15**	**0.2%**	**7,978**	**100.0%**
	Population[c] *(million, %)*									
low	14.7	24.3%	3.0	4.9%	0.3	0.6%	0.0	0.0%	**18.0**	**29.8%**
medium	11.1	18.3%	4.6	7.7%	2.1	3.4%	0.1	0.2%	**17.9**	**29.6%**
high	19.8	32.7%	1.2	2.0%	0.7	1.1%	0.0	0.0%	**21.8**	**35.9%**
very high	2.7	4.5%	0.1	0.2%	0.0	0.0%	0.0	0.0%	**2.9**	**4.7%**
Total	**48.4**	**79.8%**	**9.0**	**14.9%**	**3.1**	**5.1%**	**0.1**	**0.2%**	**60.6**	**100.0%**

Earthquake vs flood 2/2





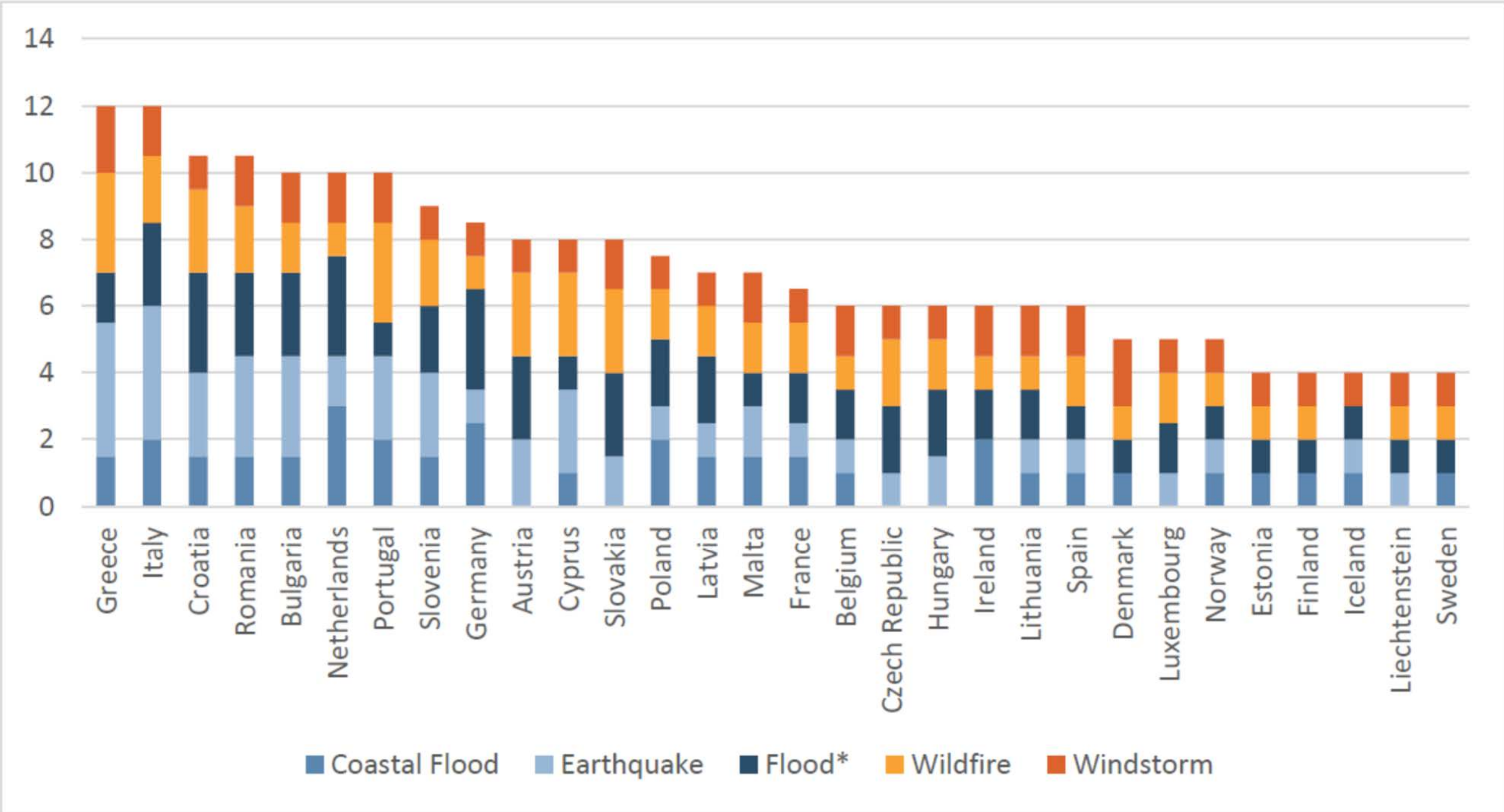
The independence of the two risks is clearly visible on a geographical map

The under-insurance of natural risks

- 60% of households' wealth is in the real estate
- Insured houses:
  3.9% earthq, 2.7% flood, 4.9% both = 11.5% (March 2022)
  (higher level for commercial buildings)
- Determining factor of the under-insurance gap (fire insurance 52%):
  - Insurance illiteracy
  - Optimism bias
  - Short-lived post-disaster effect
  - State intervention (charity hazard): 4-5 bil€ per year
    - Uncertainty about size and time of ex-post intervention
    - Wealth transfer from non-owners to landlords (regressive fiscal policy)

	num	annual income
non owner family	8 mil	19 054
owner family	17.5 mil	35 693

Protection gap score for 5 perils (dec. 2022)

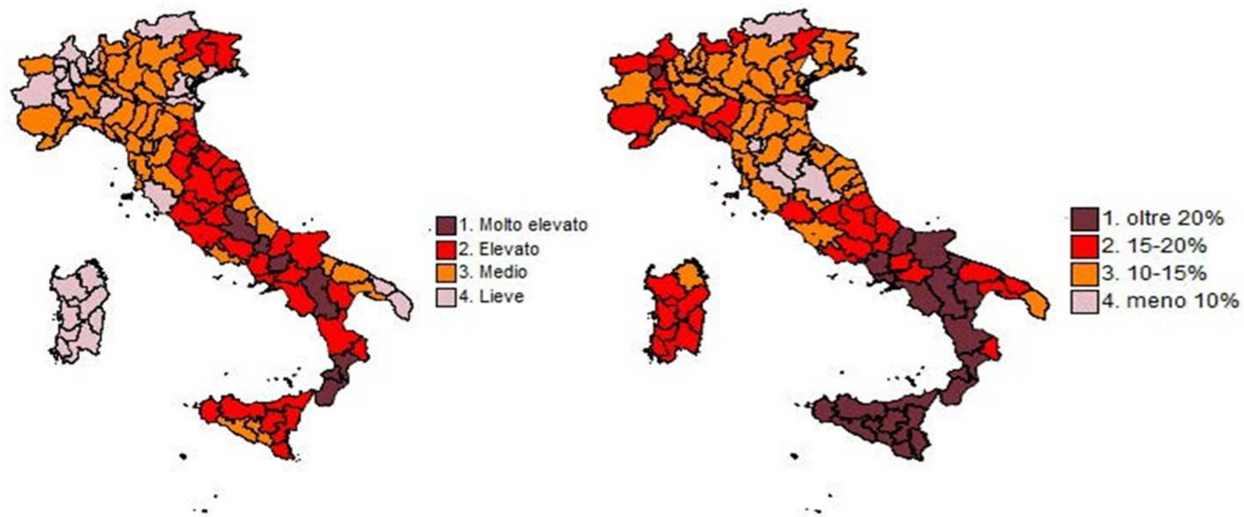


Source: Dashboard EIOPA

Two relevant problems

- Low level of building maintenance

(a) Rischio sismico	(b) Degrado conservativo degli edifici residenziali *(% edifici residenziali in stato di conservazione mediocre o pessimo)*



Correlation btw earthquake risk and degree of neglect of residential buildings

- Illegal building practices (location + building criteria)
  (Southern Italy: illegal/legal=48%)

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CAVEAT

- According to INGV evaluation, the current earthquake database should be updated (work in progress)

The new measurements will express higher level of risk and hazards

- We are not geophysicists. Many thanks to INGV (esp President Prof. Carlo Doglioni) and UniNa (Prof. Warner Marzocchi) and many others (but mistakes are ours)

Earthquake measures

- Magnitude as amplitude (height) of seismic waves
  - Richter (1935) scale (local magnitude M_L) 0-9
- Magnitude as moment (torque) of the earthquake
  - Kanamori (1977) moment magnitude (M_W) 0-13
- Intensity: Mercalli (1902) – Cancani (1903) – Sieberg (1930) MCS
  - I-XII scale estimating the effects on people and buildings
- Peak Ground Acceleration / Velocity (PGA, PGV)
  - Maximum acceleration / velocity at the ground level during earthquake shaking
  - Acceleration: 1g= 9.81 m/s2 velocity: cm/s

https://emidius.mi.ingv.it/CPTI15-DBMI15/query_place/

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The INGV approach to seismic risk

- Surface of Italy divided into a uniform grid by 16,852 points
- Nine *PGA* values estimated for every point *z* over a 50-year horizon
- Each *PGA* value corresponds to nine exceedance probabilities:

$$\alpha_{z,50,PGA} \in \{2\%, 5\%, 10\%, 22\%, 30\%, 39\%, 50\%, 63\%, 81\%\}$$

$\alpha_{z,50,PGA} \equiv$ probability of at least one event with PGA equal or higher than the assigned PGA over 50 years

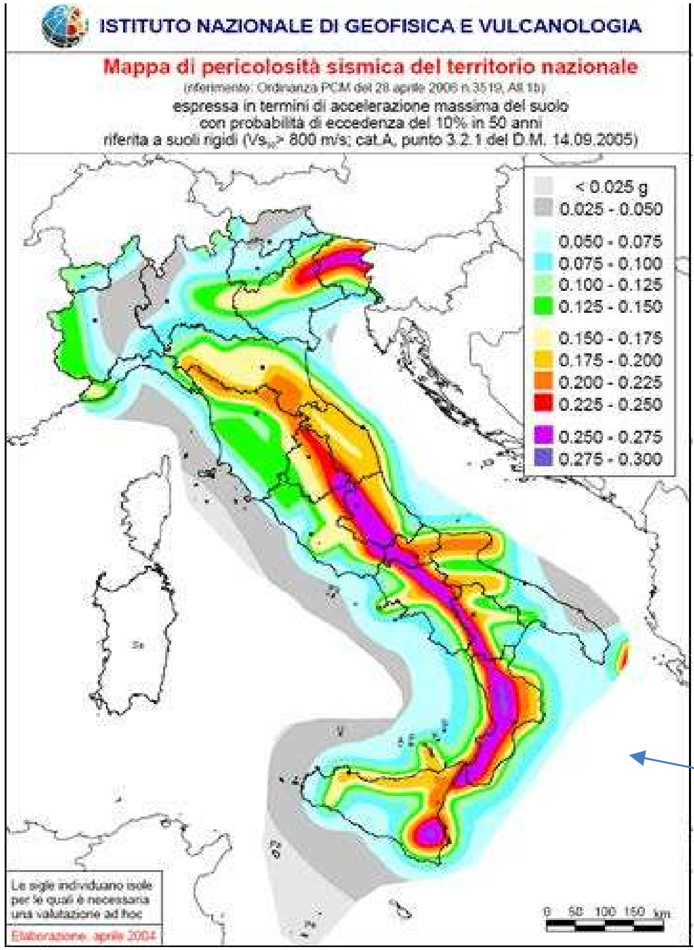
- $\lambda_{z,50,PGA}$ ≡average yearly number of events with *PGA* higher or equal than the assigned *PGA*

By using Poisson's law:

$$\lambda_{z,50,PGA} = -\frac{\ln(1-\alpha_{z,50,PGA})}{50}$$

- Return period: $n_{z,50,PGA} \equiv \frac{1}{\lambda_{z,50,PGA}}$ =average number of years between two consecutive events

Maps of PGA (INGV)



Estimated distribution of PGA given z and horizon (50 years) from which:

$$PGA_{z,50,10\%} = max\left\{PGA_z: \quad Prob\left(\left[\sum_{t=1}^{50} I_{PGA_{z,t}>PGA_z}\right] \geq 1\right) = 10\%\right\}$$

Max PGA for which the prob of at least 1 event with PGA greater than the given PGA is 10%

PGA with 10% exceedance prob in 50 years

An insurance-based approach

INGV measure of seismic risk useful for civil engineering projects

It provides the maximum PGA, occurring in 50 years with 10% probability, the buildings have to withstand

For insurance pricing we need:

the probability of a seismic event (with **intensity** ≥ H) over 5-10y

Intensity: a scale (MCS) that evaluates the building damages (*PGA* not completely suitable)

From shakes with given probabilities to probability of damages

Two tranformations required to go beyond the INGV approach

From ***PGA/PGV*** (local evaluation of ground shaking) **to *MCS* (**macroseismic intensity**)**

From a **map of events** of given probability and given horizon
to a **probability distribution** over an arbitrary m-year horizon: m<50

$$\alpha_{z,m,\overline{MCS}} = Prob\left(\left[\sum_{t=1}^{m} I_{MCS_{z,t}>\overline{MCS}}\right] \geq 1\right)$$

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The estimation method (1)

PGA/PGV → MCS → λ → α = Prob

Shakemap INGV 2009-2017: {PGA_k, PGV_k} →

$$ln(PGV_k) = \gamma_0 + \gamma_1\, ln(PGA_k) + \varepsilon_k$$

$$PGA_{z,50,\alpha_{50}}, \alpha_{50} \in \{2,5,10,22,30,39,50,63,81\}$$

$$\{\hat{\gamma}_0, \hat{\gamma}_1\} \rightarrow \widehat{PGV}_{z,50,\alpha_{50}}$$

Model that produces *MCS* [Faenza, Michelini, 2010]

$$MCS = 1{,}68 \pm 0{,}22 + 2{,}58 \pm 0{,}14 \log_{10}(PGA)$$
$$MCS = 5{,}11 \pm 0{,}07 + 2{,}35 \pm 0{,}0{,}9 \log_{10}(PGV)$$

The estimation method (2)

Application of the model of Michelini and Faenza (2010)

Original best-fit rule

$$MCS = \begin{cases} MCS_{PGA} \ \ if \ MCS \leq 6 \\ MCS_{PGV} \ \ if \ MCS > 6 \end{cases}$$

The rule requires the knowledge of *MCS*, not available for us

Since we always have in our data: $MCS_{PGA} < MCS_{PGV}$, we use the distance of MCS_{PGA} and MCS_{PGV} from 6 as a credibility measure and we choose the value more distant from 6 according to the rule:

$$MCS = \begin{cases} MCS_{PGA} \ if \ 6 - MCS_{PGA} > MCS_{PGV} - 6 \\ MCS_{PGV} \ if \ 6 - MCS_{PGA} < MCS_{PGV} - 6 \end{cases}$$

We can now select which of the two equations of the model to use and derive a lower, a central ($MCS_{z,j}$) and an upper value of *MCS* for every point *z* of the grid and every exceedance *j*

The estimation method (3)

$$ln(\lambda_{z,j}) = \beta_0 + \beta_{1,z} + \beta_2 MCS_{z,j} + \varepsilon_{z,j}$$

Fixed effect panel model

↓

$$\hat{\lambda}_{z,j} = \hat{\lambda}_{z,j}(MCS) = \hat{f} e^{\hat{\beta}_0 + \hat{\beta}_{1,z} + \hat{\beta}_2 MCS}$$

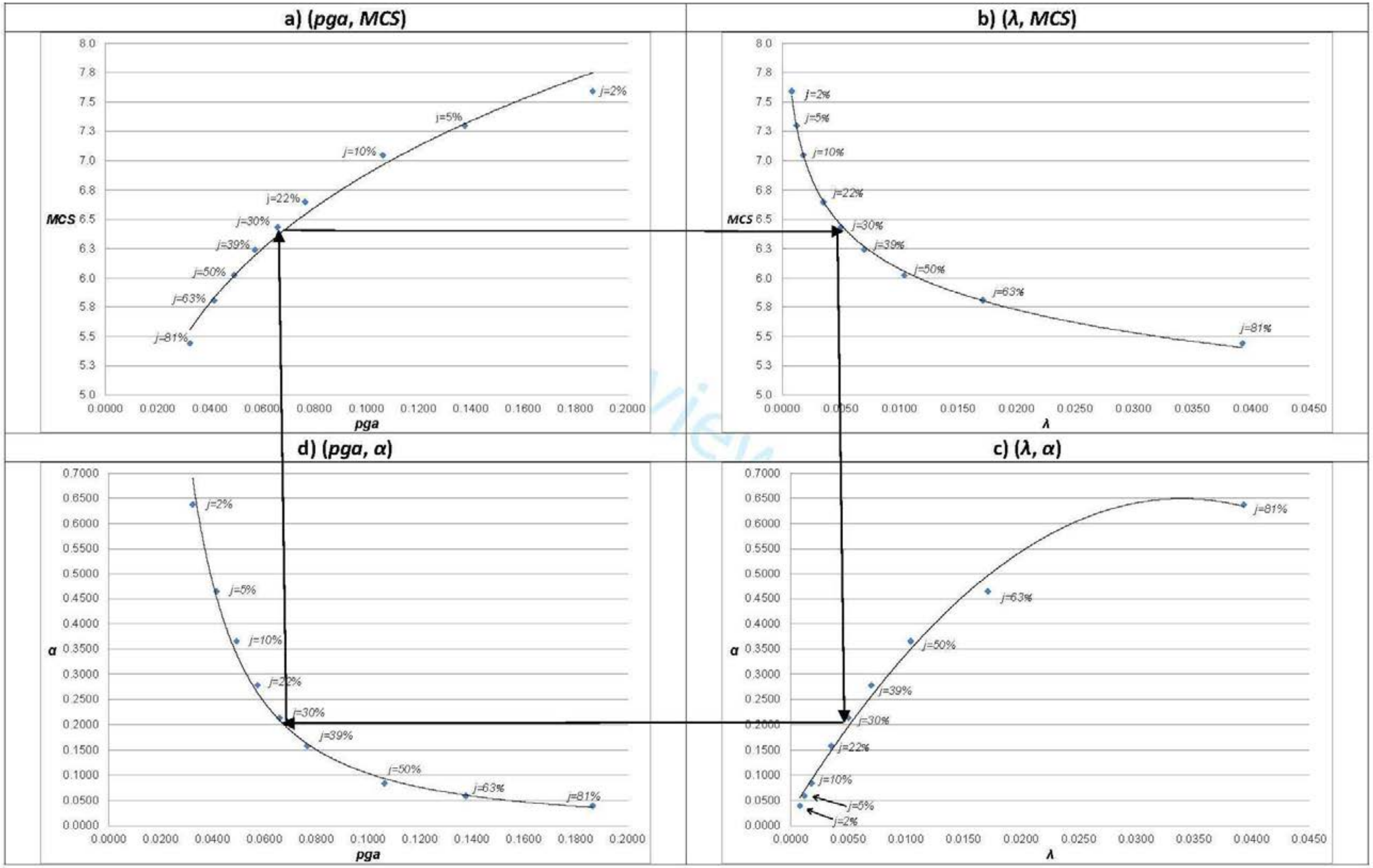
$\alpha_{z,m}(\overline{MCS})$ can be computed for all the values of $\overline{MCS}$ of interest

↓

$$\alpha_{z,m}(\overline{MCS}) = 1 - e^{-m\hat{\lambda}_{z,j}(\overline{MCS})}$$

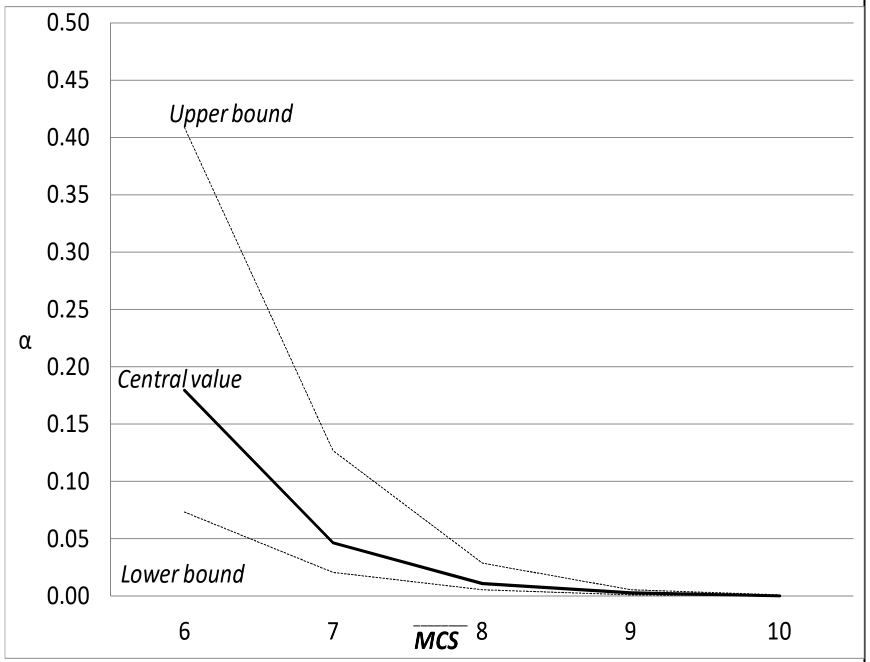
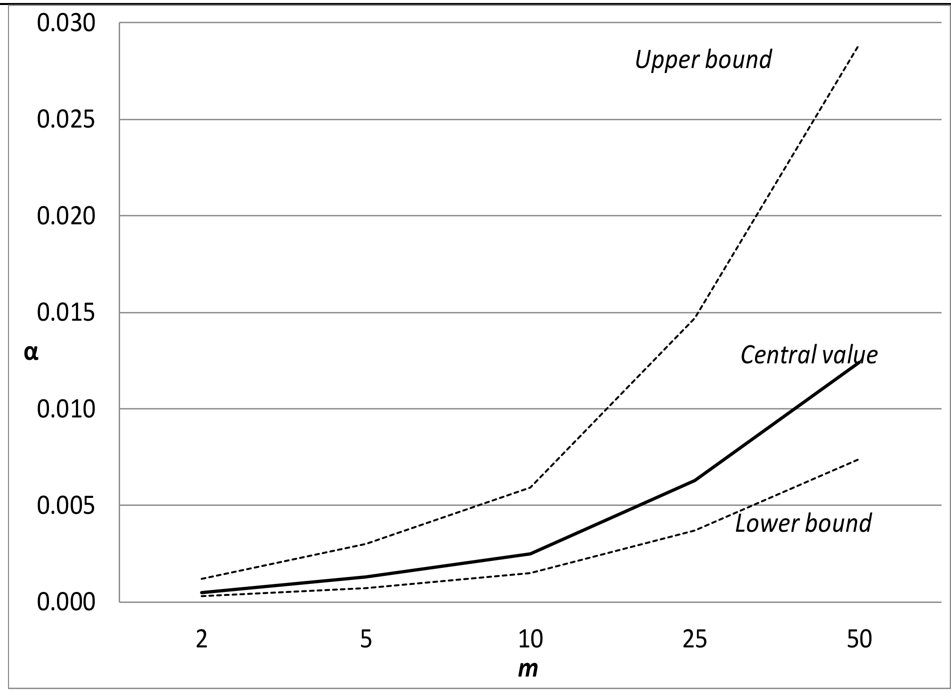
Categorized values of $\alpha_{z,m}(\overline{MCS})$ can be represented on a map

Synthetic representation of the model



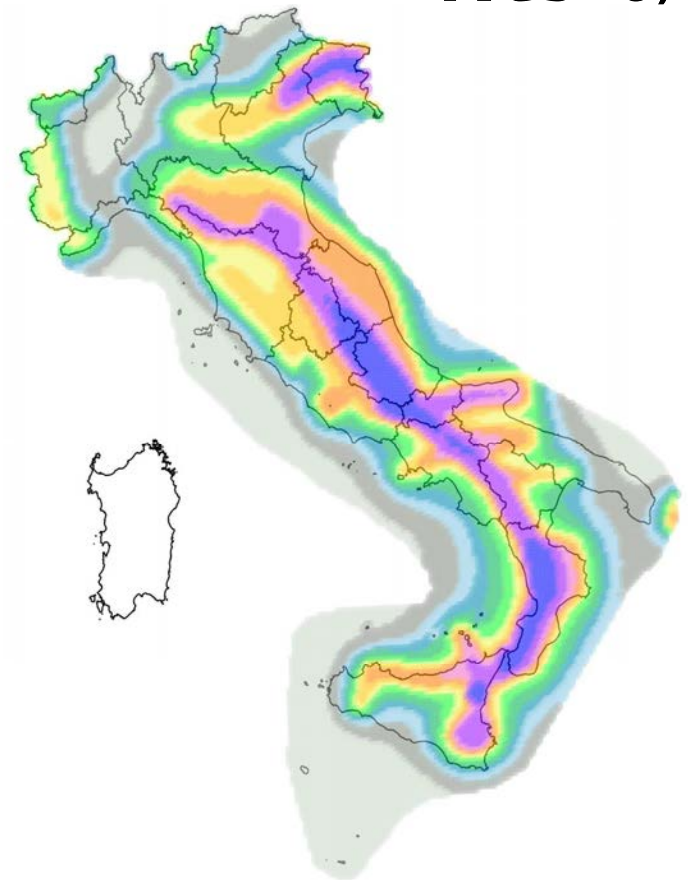
Estimation uncertainty

Uncertainty of the seismic risk measure

Bivariate plot of $\{\bar{\alpha}_m(\overline{MCS}), \overline{MCS}\}$[(a)] for m=10 *(mean values over all the points of the INGV grid)*	**Bivariate plot of $\{\bar{\alpha}_m(\overline{MCS}), m\}$[(a)] for $\overline{MCS} = 9$** *(mean values over all the points of the INGV grid)*
	

Map of probabilities 1/2

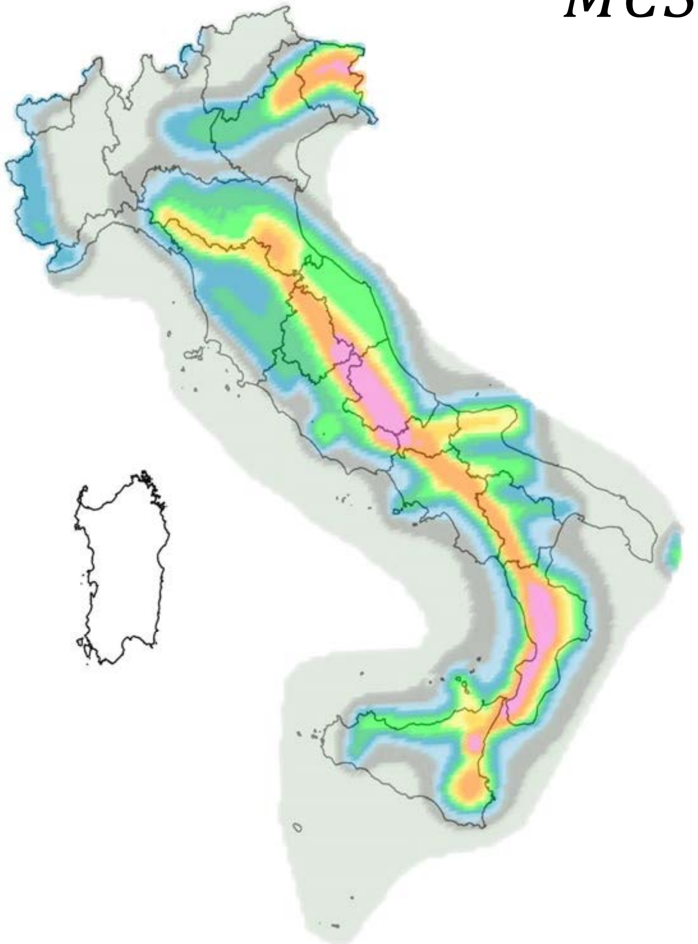
$\overline{MCS}$=6, m=10 years



Probability	Population at risk	
	millions of units	%
α_{10}<=2.5%	4.8	8.0%
2.5%<α_{10}<=5.0%	8.2	13.8%
5.0%<α_{10}<=7.5%	7.6	12.9%
7.5%<α_{10}<=10.0%	6.0	10.1%
10.0%<α_{10}<=15.0%	8.6	14.5%
15.0%<α_{10}<=20.0%	4.5	7.5%
20.0%<α_{10}<=25.0%	4.5	7.6%
25.0%<α_{10}<=30.0%	3.5	5.9%
30.0%<α_{10}<=35.0%	4.7	8.0%
35.0%<α<=40.0%	2.4	4.0%
40.0%<α_{10}<=50.0%	2.9	4.9%
α_{10}>50.0%	1.7	2.8%

Map of probabilities 2/2

$\overline{MCS}$=9, m=10 years



Probability	Population at risk	
	millions of units	*%*
α_{10}<=0.05%	17.4	29.4%
0.05%<α_{10}<=0.10%	16.0	26.9%
0.10%<α_{10}<=0.15%	6.2	10.4%
0.15%< α_{10}<=0.20%	5.4	9.2%
0.20%< α_{10}<=0.25%	2.9	4.9%
0.25%< α_{10}<=0.30%	4.8	8.2%
0.30%< α_{10}<=0.35%	2.0	3.3%
0.35%< α_{10}<=0.40%	1.5	2.5%
0.40%< α_{10}<=0.50%	1.9	3.2%
α_{10}>0.50%	1.2	2.1%

34.8 million housing units (value: 5,510 billion of euros)

$v_{c,l,p}$= value of the housing units for municipality *c*, building structure type *l* and preservation state *p*

$n°_{c,1,\overline{MCS}}$ = stochastic yearly number of $\overline{MCS}$-intensity seismic events in municipality *c (Poisson distribution with frequency parameter* $\lambda°_{c,1,\overline{MCS}}$*)* $\lambda°_{c,1,\overline{MCS}} \cong \lambda_{c,1,\overline{MCS}} - \lambda_{c,1,\overline{MCS}+1}$

$d_{\overline{MCS},l,p}$= random share of value of the building with structure *l* and preservation state *p* damaged by an $\overline{MCS}$-intensity seismic event (Beta distribution with alfa=1)

$$\tilde{A} \equiv \sum_{c} \sum_{\overline{MCS}} \sum_{l} \sum_{p} v_{c,l,p}\, d_{\overline{MCS},l,p} n°_{c,1,\overline{MCS}}$$

Aggregate yearly loss distributed according to a cdf F_A

Two variables relevant for insurance purposes

$$AEL(n) \equiv min\left\{L: 1 - F_A(L) = \frac{1}{n}\right\}$$

Aggregate Exceedance Loss: minimum yearly damage exceeded with $\frac{1}{n}$ probability

$$AAL = \sum_{c} \sum_{\overline{MCS}} \sum_{l} \sum_{p} v_{c,l,p}\, \bar{d}_{\overline{MCS},l,p} \lambda°_{c,1,\overline{MCS}}$$

Average Annual Loss: represents the pure-risk premium to be paid for the hypothetical insurance policy

A simulation over 6 alternative scenarios (3 building types & 2 kinds of damage compensations)

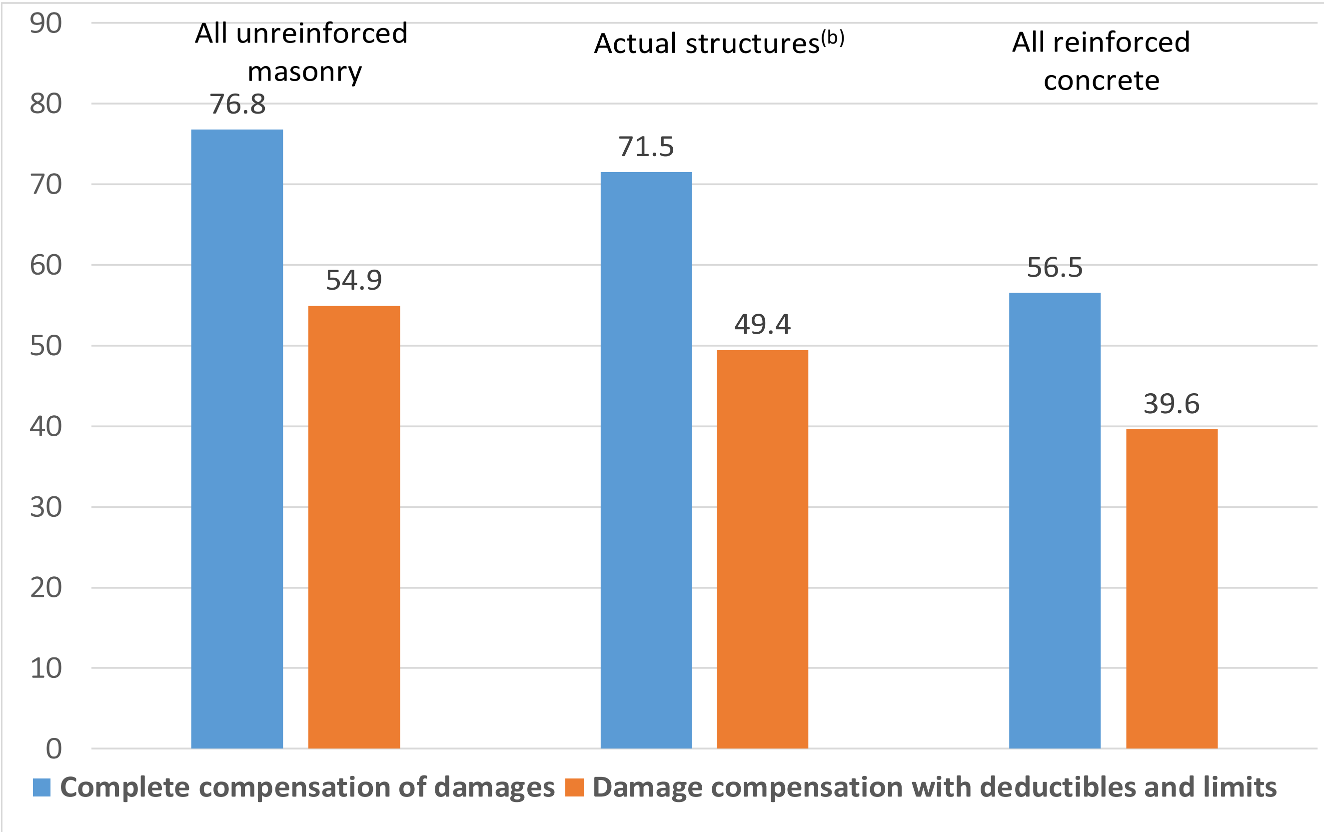
Simulation results (millions)

	Return period	Compensation of damages					
		Complete compensation			Compensation with deductibles and limits[b]		
		Type of building structure					
		All unreinforced masonry	Actual structures[a]	All reinforced concrete	All unreinforced masonry	Actual structures[a]	All reinforced concrete
		AEL					
	10,000	144,142	107,497	103,737	89,753	83,571	68,919
	5,000	124,731	89,589	88,487	81,432	74,156	60,830
	1,000	74,220	61,760	51,152	52,368	45,651	38,806
	500	58,677	49,235	41,414	42,062	35,565	31,156
	250	47,619	41,056	34,340	33,541	29,252	24,768
99.5%	200	44,544	39,122	32,523	31,563	27,702	23,134
	100	37,413	33,536	27,344	26,357	23,670	19,383
	50	32,295	29,242	23,807	22,681	20,489	16,711
	25	28,066	25,549	20,594	19,610	17,840	14,412
	10	21,478	19,638	15,809	15,051	13,659	11,041
	5	14,158	12,944	10,398	9,918	9,099	7,312
	2	4,040	3,713	2,968	2,813	2,569	2,066
AAL	Average	4,294	3,915	3,156	3,440	3,136	2,528
AAL	Std. dev.	3,146	2,805	2,592	2,258	2,092	2,283

(a) Istat 2011 census

(b) Ivass survey: limit 65%, deductible 6%

AAL per 100,000 euros of insured value



Simulation results comparable with those obtained from 2 commercial models (RMS, Swiss RE)

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Mutuality effect

CRESTA zone		Building structure								
Level of CRESTA zone	name of CRESTA zone	**All unreinforced masonry**			**Actual structures**			**All reinforced concrete**		
1	Piemonte, Valle d'Aosta, Liguria	35.0	31.7		32.6	29.6		25.9	23.7	
2	Torino	26.4			24.8			20.1		
1	Lombardia, Emilia-Romagna	56.1	48.6		52.9	46.0		43.4	37.8	
2	Milano	13.5			12.8			10.7		
2	Bologna	105.4			100.1			83.2		
1	Veneto, Trentino-A.A., Friuli-V.G.	66.9	74.5		63.0	70.2		51.4	57.3	
2	Udine e Pordenone	145.8			137.5			112.5		
Northern Italy				**50.4**			**47.5**			**38.8**
1	Toscana, Lazio	95.8	88.3		90.0	82.9		73.0	67.2	
2	Roma	77.8			73.2			59.3		
1	Marche, Umbria, Abruzzo, Molise	134.8	144.0		126.5	135.1		102.0	108.8	
2	L'Aquila	226.3			211.7			169.6		
Central Italy				**105.0**			**98.6**			**79.7**
1	Puglia	34.4	52.2		32.0	48.4		25.3	37.8	
2	Foggia	132.9			122.6			94.5		
1	Campania, Basilicata, Calabria	132.2	148.1		121.4	135.3		92.2	101.3	
2	Napoli	114.4			103.7			76.1		
2	Benevento e Avellino	180.2			167.5			131.6		
2	Potenza	169.3			155.9			119.5		
2	Catanzaro e Reggio Calabria	250.0			226.5			165.5		
1	Sicilia	70.4	122.0		64.2	111.1		47.8	82.5	
2	Messina e Catania	202.8			183.8			134.6		
2	Siracusa e Ragusa	123.2			114.0			88.4		
1	Sardegna	---	---		---	---		---	---	
Southern Italy and major islands				**109.5**			**100.0**			**75.0**
	Range	236.5	116.4	54.6	213.7	105.7	51.1	159.0	85.2	41.0
	Coefficient of variation	56.9	47.3	35.1	56.2	46.7	35.0	54.7	45.1	34.6
	Total for Italy			76.8			71.5			56.5

North 50€

Center-South 110€

Some policy issues

Three pillars needed to implement effective policies of natural catastrophe risk reduction (European Commission, 2016):

- scientific understanding of the underlying risk
- consistent communication of risk
- an optimal disaster risk management (DRM)

↓

Insurance

Three policy options

I: no intervention (freedom of choice; charity hazard; ex post management; adverse selection)

II: semi-mandatory insurance e.g. for fire (home) policies (coverage 52%)

III: compulsory insurance for natural risks for all homeowners (insurance, reinsurance, State)

Three policy options

0% **I**: no intervention (freedom of choice; charity hazard; ex post management; adverse selection)

1% **II**: semi-mandatory insurance e.g. for fire (home) policies (coverage 52%)

99% **III:** compulsory insurance for natural risks for all homeowners (insurance, reinsurance, State)

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Three policy options

94% **I**: no intervention (freedom of choice; charity hazard; ex post management; adverse selection)

5% **II**: semi-mandatory insurance e.g. for fire (home) policies (coverage 52%)

1% **III:** compulsory insurance for natural risks for all homeowners (insurance, reinsurance, State)

Future work

- PGA / PGV as function of soil type
  Thanks to Geo-engineers of Federico II University (Reassess sw)

- Extension from constant λ_z to stochastic λ_z with a spatial distribution