A Theoretical Examination of Earthquake Related Decision Making.

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Introduction.

"According to the international convention agreed by an expert meeting organized by the United Nations Office of the Coordinator of Disaster Relief (UNDRO) in 1979, the term *earthquake risk* refers to the expected losses to a given *element at risk*, over a specified future time period."[1]

The process of seismic risk assessment consists essentially of two steps.[2] The first one is seismic risk determination, and the second one is seismic risk evaluation.

The aim of this paper is to analyze the logic of the economic behavior of the protagonists of the seismic risk evaluation process, to try to understand in which way is possible to increase the efficiency of this process.

Seismic risk determination.

The seismic risk determination involves three sub-steps. The first one is seismic hazard determination. The seismic hazard of an area can be defined as the probability distribution of a vector random variable j representing the earthquake intensities in the same area within a specified time. The second sub-step involved in seismic risk determination is seismic risk exposition determination. Seismic risk exposition refers to the quantity and to the kind of human settlement elements existing in the area under consideration. The third sub-step involved in the seismic risk determination process is seismic risk vulnerability determination. Seismic risk vulnerability of an element exposed to a seismic hazard can be defined as the degree of loss that the element itself would suffer, if a given intensity earthquake occurred.

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[1] See Coburn A. Spence R. (1992): "Earthquake Protection," John Wiley & Sons, Chichester, England. page 254.

[2] See Wyner A.J. (1982): "Earthquakes and risk level decision making by California local governments," Institute of Governmetal Affairs, University of California, Davis, California.

The results of those three sub-steps together allow us to quantify the seismic risk that an element i faces in a given time. This seismic risk $\mathbf{R_i}$ can be expressed as:

$$\mathbf{R_i = \int_j \{P(j) * [V_{ij} + \Sigma_{k \neq i} H_{ik} V_{ij}]\} dj} \quad \mathbf{(1)}$$

Where $\mathbf{P(j)}$ is the probability of occurrence of an earthquake of severity j, $\mathbf{V_{ij}}$ is the vulnerability of the element i to an earthquake of intensity j, $\mathbf{H_{ik}}$ is a cross-vulnerability coefficient that represents the damage that an element i will suffer from a unit loss to the element k, and $j \in \{0, \text{Values of the Richter's scale}\}$.[3]

To quantify the seismic risk that a community as a whole faces is not a trivial matter. As a principle, it would be enough simply to sum up the seismic risk faced by the single community constituting elements, so the seismic risk **R** would just be equal to:

$$\mathbf{R = \Sigma_i R_i} \quad \mathbf{(2)}$$

The problem that we face here in practice it is in the choice of the elements to consider in this summation. The linkages among the various elements that constitute a modern society are so complex that it makes it difficult to understand the extent of the damages the can spread on the surrounding area.

The determination of the seismic risk level existing in a community is a technical-scientific process that involves people trained for this purpose who are usually not personally affected by this determination. For this reason, we can be waiting from these people for a behavior leaded only by their technical-scientific background, without any personal interest influence.

[3] See also Coburn A. Spence R. (1992):"Earthquake Protection."

Seismic risk evaluation.

The situation changes when we start talking about the seismic risk evaluation process. In this step of the seismic risk assessment non-technical actors evaluate the conclusions reached by the protagonists of the seismic risk determination process, and decide how to implement them. We can realistically assume that in this phase the different objectives and beliefs of the various protagonists involved will influence their behavior.

The protagonists of the seismic risk evaluation process are threefold: politicians, citizens, and the society as a whole. Those protagonists have logic that sometimes can diverge among them. We can think that the results of this process will depend upon that logic and upon two other factors: the personal understanding on the topic by politicians and citizens, and the ties existing between them. The third actor of the process, the society as a whole, is a mute one that is institutionally represented by politicians.

Given the existing technology level, it is possible to reduce the seismic risk faced by a human settlement located practically anywhere to any desired value. Naturally, if we were in an ideal world where resources were not scarce, the only morally acceptable decision would be to reduce the seismic risk faced by any human settlement to the value of 0. By doing so, people would not have to worry anymore about the possible occurrence of earthquakes, because they will not have to suffer any more damages from them.

Unfortunately, in the real world resources are scarce, so their allocation to a specific activity prevents them from being allocated somewhere else. If a society had as its only goal the protection of people and things from each possible source of danger, then it would probably allocate for this purpose a large share of its available resources. Because of that, this society might not have enough available resources to spend in other sectors that are also important to warranty the welfare of its members, like food production. This kind of allocation decision would not be efficient, because it would not warranty the maximization of the social net benefit arising from the allocation of the available resources. The benefit that this society would enjoy from its safety would have the cost of a consequential resource under-allocation in the other sectors.

The only way for a society to maximize its social net benefit is to determine the amount of resources to be allocated to each different sector according to the results of a benefit cost analysis. The socially efficient resources allocation will be the one that will equalize the marginal net benefit of the investments in each sector. Such allocation decision rule might have the effect to leave some threat for people and things' safety, but this is the necessary price to pay to have a resource allocation efficient from a social point of view.

Following any of the two allocation decision rules described above, as well as any other possible decision rule, at the end we will come out with an amount of resources to be allocated in people and things' protection. After setting this amount, it will be necessary to apprise the different available options capable to achieve this goal. We do not have to forget here that to pursue seismic safety is not the only possible kind of people and things' protection activity. There are also other important ways to protect people and things, like traffic safety. To be able to allocate the resources available for people and things' protection in the most effective possible way, at this point we will need to perform a cost effectiveness analysis among the different options available. The result of this analysis will give us the efficient amount of resources to be allocated to each of these options, so also the efficient amount to be allocated to seismic risk reduction activities.

After determining in this way the amount of resources to be allocated to seismic risk reduction activities, it will be necessary to decide the forms of this allocation. There are two main possible forms of resource allocation to seismic risk reduction activities. One possibility is to make both new and existing buildings more earthquake resistant through modification of their physical framework. This possibility is usually implemented throughout the enactment of Building Codes. The other possibility is to use the urban planning for seismic safety purposes without particular interventions in the framework of the single building.[4] The choice between those two options, or among different mixes of them, will depend on both economical and technical factors.

From an economic point of view, given that with a good approximation the latter option is more land consuming than the former, the choice between them, or among different mixes of them, will heavily depend on the land market value in the area under consideration. From a technical point of view, we have to notice that only in the case of a highly seismic risk area it can be necessary to use both options together at their full potentiality to be able to achieve an acceptable seismic safety standard. In all the other cases there is always the possibility to choose among different levels of restrictions from urban planning and Building Codes. All these problems are still part of an open field; hopefully future contributions will lead us to new and more effective solutions to them.

Up to this point, the performed analysis considers the point of view of the society as a whole. We have to remember that in the real world a community is composed by people that live in a particular place and managed by other people that often, but not always, live also in the same place. Members of both groups will have their own personal interests that may not correspond with the interest of the community as a whole.

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[4] See Messori L. (1993): "I rischi naturali nella pianificazione territoriale,"(The Natural Risks in the Territorial Planning) Unpublished Ph.D. Dissertation, University of Reggio Calabria, Italy.

Rationally behaving household members of a community will have the common goal to maximize their total utility **U**. We can think to this total utility as a function of the consumption of a composite commodity **Bt,** and of the seismic risk that the household faces **R**, defined here as the sum of a household's risk aversion measure and of the treat that the earthquake causes for the human life, given that **Bt** is already an expected value, so inclusive of the material aspect of the seismic risk as defined by UNDRO.

$$U = U(Bt,R) \quad (3)$$

The marginal utility U_{Bt} of **Bt** is supposed to be positive, while the marginal utility U_R of **R** is supposed to be negative. If some form of seismic risk reduction activity takes place in the community, its effect on the utility of a typical household will have two components working in opposite directions.

The net cost **C** of those activities, expressed in units of the composite consumption commodity **Bt**, will decrease the household's utility by the amount $U_{Bt} * C$. The risk reduction ΔR, consequence of the performance of the seismic risk reduction activities, will increase the household's utility by the quantity $U_R * \Delta R$. So, the effect ΔU of the seismic risk reduction activities on the household's utility will be equal to:

$$\Delta U = U_{Bt} * C + U_R * \Delta R \quad (4)$$

Rationally behaving people will support those seismic risk reduction activities if they estimate that ΔU will be positive. Given that **C** is a data of the problem, because represents the result of a political decision, and that according with the classical microeconomics theory rationally behaving households know U_{Bt} and U_R, the element of uncertainty in this formula is the value of ΔR. Given that the measure of the risk level has some level of uncertainty even at a scientific level, we can suppose that this uncertainty will be even greater at the common knowledge level. As a consequence, the support of the risk reduction activities by the public opinion will heavily depend both on the spread of earthquake related information and on the public evaluation of the uncertain parameters involved. There are several factors that can influence this evaluation: one of them is the amount of time passed from the last earthquake in the area. Unfortunately the collective memory tends to forget very quickly this kind of events, so that even a generation after their occurrence they can be already deleted in the people's collective memory.

What is also interesting to point out here it is that $\mathbf{U_R}$ is diminishing at a higher rate than $\mathbf{U_{Bt}}$. This happens because there exists a level of seismic risk that is considered *socially acceptable*. Beyond this level people do not care anymore about any further seismic risk reduction, because they do not care anymore about the considered components of the seismic risk (in most areas, the probability of death caused by an accident occurring while walking on the street is greater than the probability of death caused by the occurrence of an earthquake, but nobody even thinks that to walk on the street is a dangerous activity).

Coburn (1992) says that the *socially acceptable* human life seismic risk level in the United Stated is an annual level of one death per ten million people exposed. According to this framework, the second term of equation (4) for a typical American household will be equal to 0, so an earthquake human life safety policy would not get the nationwide support of the majority. This seems to be a realistic conclusion.

The situation from the point of view of the politicians is again different. From one side, given their position they are supposed to take care of the interest of the community as a whole. From the other side, given that they are also individuals, we can predict that they will also pursue their personal interest. If we assume that they are correct, we can suppose that their personal interest will be to achieve a level of popularity high enough to allow them to be re-elected. So under this hypothesis we can assume that their goal will be to maximize their popularity **P** [5] taking as given the performance of all their duties.

If politicians decide to implement some form of risk reduction activities, the expected value of their popularity **E(P)** will be equal to their popularity accruing from everything else P_t, minus a loss of popularity P_c due to the cost for the members of the community that the performance of any risk reduction activities will cause, plus the expected value $E(P_g)$ of the gain in popularity Pg that they will enjoy if an earthquake will occur. This relationship can be written formally as:

$$E(P) = P_t - P_c + E(P_g) \quad (5)$$

If politicians decide not to implement any form of risk reduction activity, **E(P)** will be equal to P_t minus the expected value $E(P_l)$ of the loss in popularity that they will experience if an earthquake occurs in this case. So in this case the existing relation among those figures can be written as:

$$E(P) = P_t - E(P_l) \quad (6)$$

There is an other important factor to consider in this analysis - that is time. While P_c must be paid immediately, $E(P_g)$ and $E(P_l)$ are something that will eventually accrue only in the future. "This discrepancy between short-term costs and long-term prospective benefits is the basic political dilemma that makes risk assessment decision making problematic."[6]

5 See Adams J.: Communication presented to the International Colloquium of Altafiumara (Italy), June 1992.

6 See Wyner A.J. (1982):"Earthquakes and risk level ..."

In a democratic society, the politicians' discount rate for $E(P_g)$ and $E(P_l)$ should be equal to the citizens' discount rate of the expected value of the damages caused by the occurrence of an earthquake, since both reflect a willingness to accept the risk, and the former are direct expression of the latter.

A first consideration to make here is that in the prevision of the earthquake occurrence the period of concern of the politicians is shorter than that of citizens. While citizens are concerned at least about the length of their lifetime, and even more because most of them care about the next generations, politicians, who are not at the same time part of the community, will be interested only in the period of their term.

As we saw, the behavior of everybody in the community will heavily depend on the probability that they will place on the occurrence of an earthquake in a given time. So, to reach a generally correct seismically safe behavior, it will be necessary to spread among the society the information allowing people to estimate correctly this probability.

Land use safety and the real estate market.

Because of the previous discussion, it arises that another important aspect of the earthquake related decision-making is the role that the market forces can have in the seismic risk management. The market mechanism, if the market works properly, will be able to contribute to the implementation of a safe land-use pattern internalizing the seismic risk in the market price. That means that in the seismically safe areas a properly working market will clear with higher real estate prices than in the seismically dangerous ones. The contribution of the market mechanism to the realization of a safe land use pattern will be that this prevailing of higher market prices in the safest areas will encourage their development, while the prevailing of lower market prices will discourage the development of the most dangerous locations.

As an example of well-working real estate market we can mention the Californian case. Murdoch (1993) quantifies the amount of the earthquake related price gradients for the San Francisco Bay Area for the years 1988-1990. According to its results, the hedonic price coefficient - for a dummy variable taking the value of 1 for a location outside a Special Study Zone, as defined by the Alquist-Priolo Special Studies Zones Act, and 0 otherwise - was $10,970.

On the opposite side, as an example of real estate market completely ignoring any kind of risk-related problem we can mention here the case of Italy. In this case, we do not have any quantitative study available, but our experience of this real estate market supports this conclusion.

The required conditions to use the market mechanism as a tool for a seismic safety policy are the usual conditions necessary for a free market to work. The most important one that is generally missing in the real estate market is perfect information.

In the United States where usually real estate prices somehow internalize seismic risk, there are several examples of state legislation on this field. Probably the most famous one is the already mentioned Alquist-Priolo Special Studies Zones Act (1972), that contains the requirement for real estate sellers to provide purchasers with property reports disclosing seismic and geologic hazards eventually present in the property object of the transaction.

On the other side in Italy widespread information on natural risk, and particularly on seismic risk, is insignificant and often misleading. Furthermore, there are not buyer protection laws like the ones contained in the already mentioned Alquist-Priolo Special Studies Zones Act. To gain an ally as strong as the real estate market to the objective of creating more safe built-up areas it would be necessary to provide the Italian public opinion with enough information on earthquake safety.

In the case of places where the realization of unlawful buildings constitutes a relevant part of the building activity, like Southern Italy, a well functioning real estate market could also bring an interesting side-effect. Usually, most of those unlawful buildings are self-built by their owners and future occupants, or are built by some small company hired by the owner and working under his direct supervision. Those owners generally show a good consideration for the safety of their future homes, at least when they have the financial means to do that. The proof of this attention can be found in the fact that they often take initiatives, maybe technically wrong, with the objective of increasing the safety of their houses, like the arbitrary increase, during the construction work, of the quantity of iron in the reinforced concrete.

We can deduce from this behavior that if they would be able to receive good information about the seismic safety of their parcels before buying them, then we could assume that also the development of unlawful buildings would concentrate in the most safe areas. We can also infer that a wide-spread earthquake education could work as an earthquake risk reduction tool even without the help of any other instrument.

Conclusions.

This paper highlights the importance of the seismic risk education as the basic seismic risk safety tool. It shows that a good public education is the basis for a rational seismic risk evaluation. As we said, the seismic risk evaluation is the step that practically determines type of seismic risk reduction policy, beyond any end result reached by the seismic risk determination protagonists. So we can conclude that the most effective way to achieve an optimal level of seismic risk is to spread as much as possible earthquake related information.

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