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Methodological economic assessment of Tsunamis impact in the Mediterranean area

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Summary: *This paper is an attempt to show how may be linked an interdisciplinary assessment of the impact of Tsunami between geophysical approaches and economics. It aims at showing how should be avoided preconceived ideas of what should be a tsunami from an economic viewpoint. Consequently, this paper is a cautious attempt to bring together physical data and scientific laws and economic approach is so as to build an economic assessment of coastal infrastructure under the threat of catastrophic events as Tsunami. This step is essential to assess how much financial means should be devoted to prevention. We have focused the analysis to the probabilistic part of the analysis, however, this study has to be extended to the Geographical Information System of the considered coastal area to take fully into account the potential impact of a Tsunami.*

However, once the methodology is clearly expressed it may be extended to other natural hazards as floods, storms, etc. In spite of its apparently applied concerns, the whole approach is quite theoretical because it needs a reappraisal of the real option theory to the case of extreme events.

0. Introduction

After the East Asian Tsunami of December 26th 2004, World Governments have been induced to change drastically the way they conceive prevention and protection against potential natural hazard. Nowadays, International Scientific Community, Governments, NGO, etc, are constantly questioned about how to cope with such catastrophic events[1]. However, the weak economic literature devoted to the study of extreme events shows that economic theory feels little concerns with events such as tsunamis or earthquake. Usually, it gives up the field of theoretical analysis to insurance theory. However, a catastrophic tsunami could cripple the insurance industry. As a consequence, losses of this size would hardly cause a ripple in capital market, all the more natural catastrophe losses exhibit no correlation with capital market indices[2]. That involves that an economic analysis of these phenomena should deserves attention considering that, according data of World Bank, fifty percent of the world's population currently live within sixty kilometres of the coast- i.e. at more than 3 billion people. By the year 2008, the world population will exceed 6.7 billion people, with 3.4 billion of us living in coastal areas. It is important to ensure that development does not result in people becoming more at risk from hazards. Many natural events such as flooding and erosion would be harmless if the affected land had been left undeveloped. Development in a hazard-prone area not only puts people and property in harm's way, it may worsen the effects. Building over land liable to subside into mine shafts is an example of this.

Evidences of the occurrence of potential catastrophic tsunamis in the Mediterranean area are quite strong and the question of how to deal with them is raised. The present study is an attempt to supply an economic methodology to assess economic and financial consequences for Tsunami occurrence in The Mediterranean area. Hence, tsunamis are questioning public decision under the scope of the precautionary principle. The weakest version of the precautionary principle suggests that a lack of decisive evidence of harm should not be a ground for refusing to take preventive action. This definition applies particularly to tsunamis. Linked to the previous question is the nature of protection that could fit better with the population prevention needs. Then, the assessment of the prevention investment follows quite naturally. The question of how to finance and implement remains to solve. As a

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1 For instance, United Nations General Assembly organized a World Conference on Disaster Reduction held in Kobe, Hyogo, Japan, from 18 to 22 January 2005 immediately after the catastrophic events.

[2] N.A. Doherty, Financial Innovation in the management of Catastrophe risk, Journal of Risk and Insurance, vol.64 (4), p.713-18, déc. 97

consequence, this paper will not present a positive model of real option theory “taking account” of tsunamis. Its scope will be much more limited because it is a attempt to define an interdisciplinary link between geological and geo-physical sciences and economics. It tends to show how should be chosen a probability distribution of tsunami occurrence out of any arbitrary “ad hoc” choice of extremal events representation.

1. Tsunami and the precautionary principle: a paradoxical example

Tsunami can be generated by any disturbance that displaces a large water mass from its equilibrium position. In the case of earthquake-generated tsunamis, the water column is disturbed by the uplift or subsidence of the sea floor. They have essentially coastal impacts even if they can penetrate deeply into flat territories, or streams and rivers. Such a natural hazard interacts with individual and community exposure and vulnerabilities to trigger negative social and economic impacts on a scale that goes beyond the coping capacity of the affected population.

From an economic perspective, a disaster implies some combination of *losses* in terms of human, physical, financial, and infrastructure networks. From this perspective, economic and social consequences of natural disasters are not always inevitable. At the European level a range of policy actions have taken place and are planned for the future which are designed to improve the ability to prepare for and react to disasters. Figure 1 shows that in the scale of disasters tsunami and earthquake were very important sources of human and material damages. Figure 2 shows that, specifically, Tsunamis cannot be neglected.

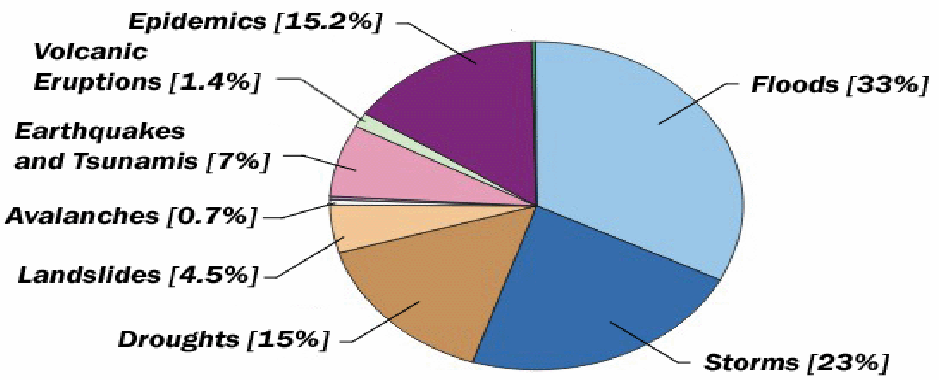

Figure 1. Natural disasters by triggering hazard averaged across the world, 1994 - 2003.
Source: EM-DAT: The OFDA/CRED International Disaster Database

Positive decisions and actions can be taken to prevent or reduce hazard pressures, to minimize the vulnerability of people and property and thus to mitigate the negative consequences of hazard events. This is the basic premise of disaster management, which refers to the development and implementation of policies and practices designed to manage and reduce the impacts of hazard events[3]. However, the nature of disaster events has to be known. Since the Indian Ocean Tsunami of December 2004, the European Union has decided to improve the management of vulnerable areas. The question is to know how achieve this task efficiently? Are networks of warning system sufficient to mitigate the consequences of tsunamis? Certainly, it is not the case. Hence, beyond, the difficulties to create this kind of network, the features of regional planning are at stake.

Why is it relevant to associate tsunamis with the precautionary principle? The above considerations show that Tsunamis are not rare events and their occurrence, in their higher levels may incur considerable damages. The question that induces the application of the precautionary principle or not by government is to know first, whether these damages are irreversible, and whether the extreme event calls for some lack of scientific certainty. It is no doubt that the precautionary principle applies to natural hazards. For instance, The 1992 Rio Declaration states, "*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"[4] How these considerations may apply to catastrophic Tsunamis?

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[3] See for instance: ICSU Scoping Group on Natural and Human-induced Natural and human-induced environmental hazards, Environmental Hazards, Report to the ICSU 28th General Assembly, Suzhou, China, October 2005.

[4] United Nations Conference on Environment and Development, June 3–14, 1992, *Rio Declaration on Environment and Development*, princ. 15, U.N. Doc. A/CONF.151/26/Rev.1, (Vol. I)

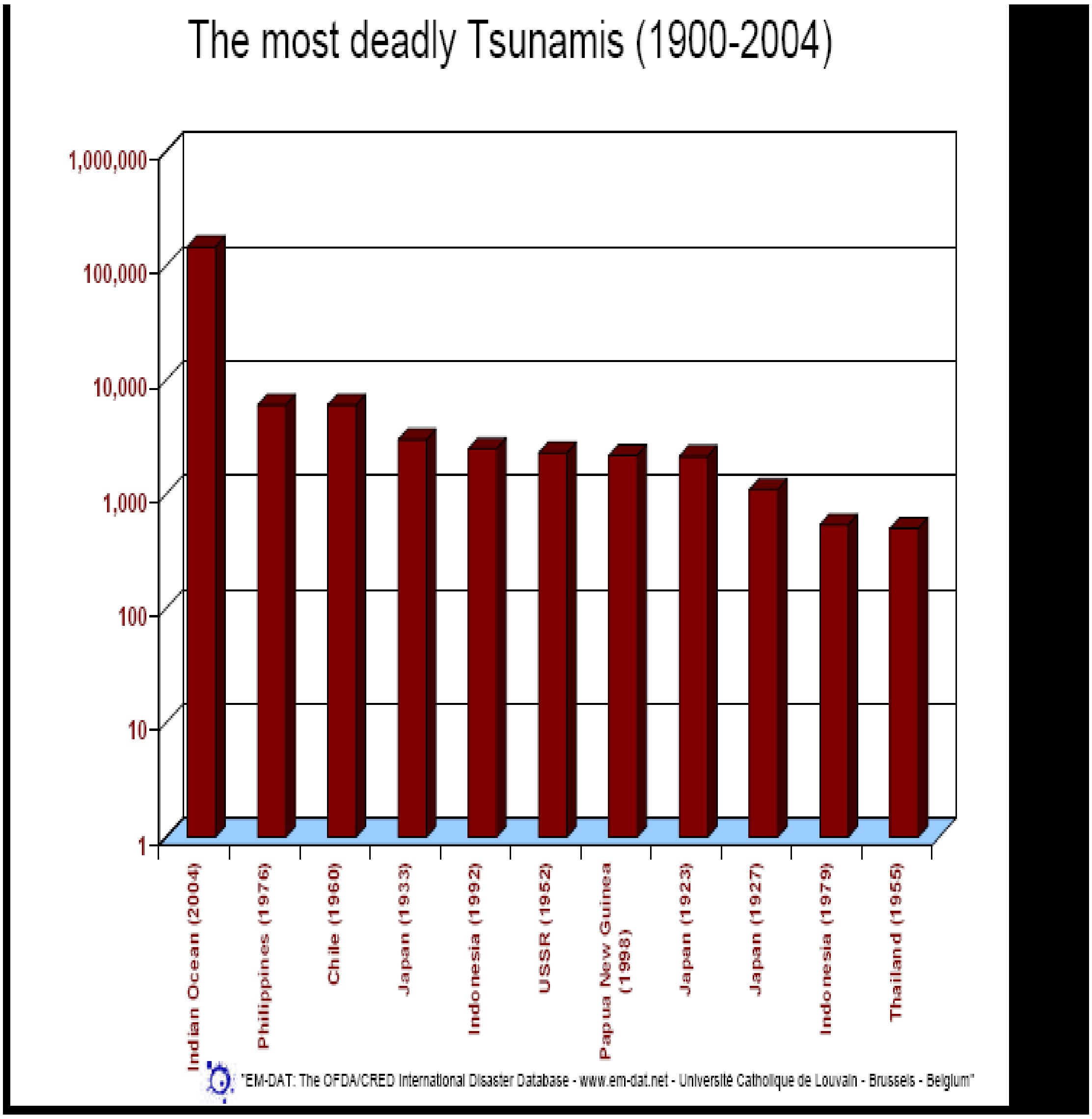

Figure 2

The question of irreversibility

The nature of irreversibility is at stake when considering Tsunamis. It is no doubt that the loss of hundred of thousands of human being is by itself an irreversible state of nature. However, close examinations of standard precautionary principle definitions show that only environmental harms are referred effectively. Hence, the quick recovery of a given area after the occurrence of a tsunami may put under question the concept of irreversibility. The matter is fundamental. At stake is the undertaking of preventive actions on the simple doubt or assumption that, potentially, tsunami of a sufficient strength may bring irreversible consequences. In fact, one the conclusion of the WCDR[5] about the 2004 tsunami shows that environment do suffers irreversibility:

"One of the key observations emerging from the rapid environmental assessments in the countries affected by the tsunami, is a lack of understanding of the effect that environmental degradation has in exacerbating the negative impacts of a disaster." Consequently, without pushing forward our argument, it appears that irreversibility in human life and damage to nature are direct consequences of the occurrence of strong tsunamis.

Irreversibility may increase because of the level of the territory vulnerability. Most of coastal territories are over-crowded with very sensitive infrastructures as building, transport networks, etc. The physical impact of a tsunami wave is extremely short duration and may cause much physical damage to property, vegetation, landscape, non-aquatic life and aquatic life. Direct damage due to high flow velocities may induce damages on coral reefs, beach formations, vegetation and the built environment. A close description of the whole set of damages may be found in Ferrando and alii(2005).

This economical, sociological, strategic vulnerability put into question the application of the precautionary principle (see for instance Sunstein (2006)). Generally, in the past, Authorities made previous implicit choices, i.e. irreversible investments, that generated the above situation. Therefore, prevention against tsunami was (and is still) inexistent. Governments, local authorities have preferred to pay nothing than to wait to acquire missing information about the consequences of tsunami. In fact, in most cases, these are circumstances that have led to this "political non-choice".

Nowadays, Authorities are facing a standard cost-benefit problem in uncertainty. Because of the lack of some relevant assessment of the consequences of the occurrence of tsunami, a loss in perpetuity of the benefits from preservation has to be expected. This has been shown years ago by Kenneth J. Arrow and Anthony C. Fisher, (1974). That means that this situation may call for applying real option theory insights.

The occurrence of the 2004 tsunami has shown to regulators that they under-estimated the irreversible losses due to tsunamis. The fact that they were uncertain about the timing and likelihood of that loss, should not have prevented them to pay a sum—an option value—in order to maintain flexibility for the future in the planning of the coastal territories. Much more recently, Fisher generalized this argument to suggesting that "[w]here a decision

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[5] WCDR, conclusion n° 6, "6.0 Implications and Recommendations for Future Disasters

problem is characterized by (1) uncertainty about future costs and benefits of the alternatives, (2) prospect for resolving or reducing the uncertainty with the passage of time, and (3) irreversibility of one or more of the alternatives, an extra value, an option value, properly attaches to the reversible alternative(s).”[6] Considering the value of a given coastal infrastructure, the question, if a cost-benefit test has to be passed, is to assess not only the impact of a tsunami of given amplitude, but equally the cost of prevention.

The question of uncertainty : the paradox of tsunami

The range of occurrence of tsunami is large from a little heigted wave to the extreme event. Concerning natural hazard and natural disaster, *Charlotte Benson and Edward J. Clay*[7] definitions’ may be adopted here. Hence, a *natural hazard* is a geophysical, atmospheric, or hydrological event that has a potential to cause harm or loss. Risk is understood to be “*a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence*”[8]. A tsunami may belong to such category of events. A natural disaster is the occurrence of an abnormal or infrequent hazard that impacts vulnerable communities or geographical areas, causing substantial damage, disruption, and possible casualties, and leaving the affected communities unable to function normally.

Tsunami is paradoxical in the sense that it is always a probable event from one hand, and on the other one, its prevention, except in countries like Japan is always very weak. For instance, in the past even the nearest one, Mediterranean Sea knew important tsunamis in almost every of its coasts. However, prevention measures are lacking, even if probability distribution about occurrence of such events do exist. As Geist and Parsons (2006) quote it:

> “*Probabilistic analysis of tsunamis is therefore not only important in determining an annualized risk as with insurance applications, but it is also important in explicitly defining the probability associated with individual scenarios.*”

The concepts of hazard, vulnerability and capacity allow the definition of risk. In order to understand these phenomena, one must study natural, technological, economic and social

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[6] *See* Anthony C. Fisher, Uncertainty, Irreversibility, and the Timing of Climate Policy 9 (Oct. 2001) (unpublished manuscript, *available at* http://www.pewclimate.org/docUploads/timing%5Ffisher%2Epdf).

[7] *Charlotte Benson and Edward J. Clay* : Disasters, Vulnerability, and the Global Economy in in Building Safer Cities: The Future of Disaster Risk, Edited by Alcira Kreimer, Margaret Arnold, Anne Carlin, The World Bank Disaster Management Facility 2003 Washington, D.C.

[8] Royal Society. 1992. Risk: Analysis, Perception and Management. London: Royal Society. 1992: 4).

systems. In some cases, models must be developed. For example, to estimate the probability of a tsunami in a region sensitive to earthquake, its design and environment must be examined in a dynamic perspective. To evaluate a social system's capacity to face up to a major accident, the regional socio-economic and institutional system must be studied, as was the case in the Vajont tragedy in Northern Italy in October 1963. There, a landslide in a dam caused an enormous wave that erased the village of Longarone, resulting in 2,000 deaths. Facing these cases, concerning tsunami in the Mediterranean area, the question is to know how to reduce risks and diminish vulnerability. This should be done by adopting measures that lower the probability of occurrence of the hazard, especially when they depend on human activity. Vulnerability and capacity generally can provide a significant potential for reducing risk. A lower vulnerability and stronger capacity allow a greater tolerance of the presence of hazards. Economic assessment of the area to protect is then necessary.

2. Real Option Theory applied to tsunamis: methodological precautions

An economic analysis of the impact of tsunami of a coastal area involves defining both the set of prevention policies and their effective costs. Among others, that involves the definition of a flexible scale according the probability and the magnitude of the event. Flexibility lies at the very core of the whole operation. That needs assessing the cost of flexibility based on newer risk measures and more sophisticated determination of the forecast risks. The demand for risk analysis and insurance for environmental catastrophes is growing because of increasing replacement costs of destroyed structures due to the steady increase in the number of people living in hazardous areas. Statistical methods are basic to risk assessments and the computation of insurance premiums. There are many models which have been used to manage and understand extreme events. In practice, a combination of models is often needed. Models used in practice are:

1) Statistical/actuarial models, where past experience is used to estimate the consequence of future events;
2) Physical models, where, for example, the consequence of a landslide or submarine earthquake is estimated from a scaled down model in a laboratory;
3) Simulation or catastrophe models, depending on computer simulations of events which include pre-determined parameters and physical constraints for

example in weather forecasts. Catastrophe models tend to make use of statistical and formulated physical models.

Methodology for assessing tsunami economic and financial consequences

Risk is a complex function of time and space. Hazards can appear in a quasi-instantaneous way, (e.g. Asian Tsunami on December 26th, 2004, killing around 300,000 people). Hence the probability of occurrence of an event can change in time. The occurrence of a hazard can have short, medium and long term consequences. Vulnerability and capacity have specific temporal dynamics. Their effects are not produced in a simultaneous way and a given hazard can have a local, regional or global impact.[9]

Natural and man-made systems are usually robust to normal perturbations. They are constructed to handle with variations of several standard deviations. However, the preparation for extreme events is costly and often incompatible with the requirements of everyday use. Therefore, it is often neglected. Historical data, scenario simulations, and expert judgment are used to develop models for uncertainty. However, these models are often converted into risk measures based on variances and co-variances (for dependent events). In some cases, it is even impossible to make statements about the mean value or standard deviation of such events, as power-law distributions are not always normalizable.

Under uncertainty, variances often do not provide adequate risk measures. Experience with financial risk measurement shows that using variances or covariances may underestimate (and in some cases overestimate) the actual risk by a sizeable factor. The emphasis is now on extreme behaviour which is often measured using value-at-risk, shortfall, etc. in the upper tail and lower tail separately. This matter of fact involves using Poisson or Levy process.

These new forms of risk measurement should be useful tools to assess risk in situations that go beyond financial or third-party risk. This is particularly true because life support networks composed of civil infrastructure are closely linked together. They can be grouped according to the following categories (Isenberg 1991; Lau 1995):

- Electricity (generation, transportation, distribution infrastructure, etc.)
- Natural gas and liquid fuels (storage, transportation, distribution infrastructure, etc.)
- Potable water and wastewater (collection, treatment,

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[9] Romerio, F. (2005), Risk analysis in the field of energy problems, Rapport de recherche du CUEPE, n°6, Université de Genève.

storage, transportation, distribution infrastructure, etc.)

- Telecommunications (broadcasting, cable transmission, distribution infrastructure, etc.)

- Transportation (road systems, public transportation systems, etc.).

Thus, these networks fulfil fundamental roles for the proper functioning of a society in ensuring essential services in health and safety of populations. When a life support network fails, the human and socioeconomic repercussions are very significant[10]. In the field of earthquake or tsunamis studies, an economic assessment involves a close scientific relationship with geologists or geo-physicians. One area outside of finance where new risk measures are being applied has been in the area of supply chain management. High-dimensional risk data with complex dependencies and nonlinear interactions will require new analytic approaches. For instance, that involves identifying structure and interactions in such situations. In fact, that would normally require unrealistically large amounts of data. Recent work on dimensionality reduction (which, on one hand, is free from rigid structural assumptions about the underlying model and, on the other hand, does not require large amounts of data) shows great promise. This will also allow better visualization of multivariate and multilevel risks along with key risk drivers.

Real options and network infrastructures

The law of large numbers has limited use when the risks are interconnected and correlated, as is the case in large catastrophes like the tsunami and Katrina. The outcome of the law of large numbers depends on the relative size of the pool of people affected over the total population. Hence, this kind of risk has to be shared across nations. Related instruments, called catastrophe bonds, have been traded in the Chicago Board of Trade since 1994. In these types of risks the correlated part of the risk is hedged through securities, while the independent risk is hedged through insurance. This may help in indicating how to define the cost of prevention policies for authorities. The great problem of option theory applied to real investment is to find financial substitutes aiming at risk hedging. For instance, reference to weather and climate derivatives may be of help and can indicate how to subrogate real

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[10] Benoît Robert, Jean-Pierre Sabourin, Mathias Glaus, Frédéric Petit, Marie-Hélène Senay A New Structural Approach for the Study of Domino Effects between Life Support Networks, in *Building Safer Cities: The Future of Disaster Risk,* Edited by Alcira Kreimer, Margaret Arnold, Anne Carlin, The World Bank Disaster Management Facility 2003 Washington, D.C.

assets[11]. Optimal flexibility strategies under certain constraints (cost, time to market, etc.) would be useful and will help parameterize flexibility. This will also allow for sensitivity analysis and stress testing to determine how best to invest additional resources and what adjustments to make as risk scenarios change.

This approach aims mainly at providing an economic methodology for assessing the consequences and costs of a Tsunami on an over-populated and developed littoral as for instance many areas in the Mediterranean area (French and Italian Rivieras, all big cities as Athena, etc..) will be exemplified as an application case. This study will attempt to justify the financial means needed to prevent the consequences of such an event. This will be made by building specific GIS chart of risk. This tool will help to build economic vulnerability map. The economic methodology needs an economic assessment of the economic losses induced by a tsunami occurrence. Hence, this research has the objective:

- First, to supply an economic assessment of vulnerability (based on the actualization of flows of the different sources of income generated on the considered area).
- Second to define the costs of prevention. This will be made by applying real options models,
- Third, to define the market organisation of insurance linked securities to have a clear idea of what may be insured by private insurance and how national solidarity may evolve in the future to cover catastrophic events.

3. Assessing the economic impact of a tsunami in a highly urbanised area: Determinants of real options

There are a variety of ways to gather, organize, and analyze coastal hazards impact and cost data. Extreme event models are very dependent on the parameterisation. Parameters can be derived from observed data; but, if an extreme event has not occurred within those data; then modelling, and hence prediction, might be difficult. Unlike normal statistical analysis, where outliers are ignored, such data are precisely what drives the extreme process. Indeed, it is the `normal' data are ignored, as these may lead to over or under-estimation of the

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[11] See for instance Chichilnisky, G. “Catastrophe Bundles Hedge Unknown Risks,” *Bests Review*, February 1996, 44-48.
Chichilnisky, G. “Catastrophe Futures: Financial Markets for Unknown Risks,” Markets Information and Uncertainty, (Chichilnisky, ed.) Cambridge University Press, 1999.

key extreme event parameters. In a simulation type model, the key parameters may vary stochastically.

The meaning of Real Options in the context of extremal events

As a consequence, the underlying determinants of options are composed of the level of economic activity as a whole of the considered area. Here options may be considered as the financial amount that should be invested to protect the whole area. This activity depends on several factors:

- One may consider direct activity associated to industry, agriculture, tourism and all commercial activities. This is linked with our direct costs assessment. This has to be assessed by local data supplied by national institutes.
- However, if a tsunami may have direct consequences, indirect ones may be expected too. Network and transport infrastructures are very sensitive about it. And a sudden event as a tsunami may paralyse the activity of an economic zone broader than that where the tsunami impact was exerted. For instance this is the case for airport or all transport networks near the sea side as in almost Mediterranean Capitals or Cities.

Hence, the underlying determinants of options are the whole of the incomes which are derived from the direct and indirect economic activity. They have to be assessed according the level of analysis that has to be achieved. If the area is narrow then we will need micro economic data, while extending the area and the indirect consequences involves to deal with much more aggregated data. We will carry out several scenarios with various degrees of probability.

The final object will be to define the whole amount of finance necessary to define a credible policy for mitigating the impact of a tsunami in the area under consideration. From an economic point of view the real options correspond to this amount that can be used who can be used and declined according to various possibilities.The approach used depends on an organization’s responsibilities, needs, interests, and specific objectives. Some of the ways in which impacts and costs might be examined are outlined here. The interrelationship among these methods and their potential utility, especially with respect to tabulating hidden costs, are also examined. Regardless of which approach or combination of approaches is used, it is important to capture all costs that are significant in assessing future vulnerability and determining the relative effectiveness of alternative mitigation strategies.

Direct and indirect costs (DC) (IC) and Long term economic costs

When classified as direct or indirect, impacts and costs are differentiated by their linkage to the event and timing. This breakdown is especially useful for capturing cascading and linked impacts. Direct impacts and costs of a catastrophe are closely connected to the event, the associated hazards (e.g. storms surges, commercial and industrial structures, public buildings, commercial and industrial structures, public buildings, water and waste treatment facilities, power generation or transmission facilities, communication facilities, automobiles, equipment of all types, bridges and surge, high winds, rain), and the resulting physical damage Pielke (1997).

Short term costs come from losses that occur at the time of the event. They may be compensated quite quickly, while long term costs are incurred far after the catastrophe. They include permanent job loss for the population and loss of tax revenues for the State and the region. While additional living expenses for individuals have to be taken into account. This involves to analyse breakdowns cost by economic sectors. An economic categorization may be assessed following the economic activity of the considered area: tourism, housing, industrial and commercial activities. Other hidden costs have to be added as household and family cost, health cost and natural ecosystems failure… Generally these costs are underestimated, by they may weight heavily on the recovery policies.

Determining insurance mechanism for reducing economic impact of a tsunami

Tsunami is a kind of catastrophic risk which is characterised by insurability[12]. In particular, if insurance offers temporal diversification, the insurance sector usually doesn’t offer a sufficient geographic diversification for catastrophe risk. More, Solvency II implies to ban temporal diversification. This involves to follows two goals:

- The first one examines how reinsurance coupled with new financial instruments and perhaps civil state can expand coverage to resident people in areas subject to catastrophic losses;

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[12] C. Gollier, About the insurability of Catastrophic risks, Geneva Papers on Risk and Insurance: Issues and Practice, 1997, 83, 177-186.

- The second shows how reinsurance and new financial instruments can be combined so that the price of protection can be lowered from its current level

The insurance linked securities development is limited in spite of its advantages in risk management, particularly concerning catastrophic risks. It faces, first, the usual difficulties linked with innovations in the insurance sector and, second, the convention of long term cooperation in the reinsurance market which limits its interest. In fact, reinsurance relationships in the trading of underwriting risk take place in an asymmetric information environment between insurer and reinsurers. Furthermore, information is revealed only over time. Information problems affect the efficiency of risk allocation, so long-term implicit contracts between insurers and reinsurers allow the inclusion of new information in the pricing of both future and past reinsurance coverage. Because of these features, the ceding company purchases a more efficient quantity of reinsurance. Specifically, such arrangements lead to more reinsurance coverage, higher insurer profits, and lower expected distress in the industry. It is, in short, socially improving[13]. As a consequence, this research aims at suggesting ways to combine both instruments to expand risky coverage and reduce the protection costs, in other words, it looks for defining some principles for designing catastrophic risk transfer systems and describing how they may be applied.

4. The needs of probabilistic tsunamis assessment analysis for real option theory

A tsunami is always probable. However the estimation of its probability distribution is quite difficult. Furthermore, the question of how it is relevant for economist to refer to probability distribution is at stake. Indeed, authors like Tinti and Armigliato (2003) consider that a tsunami prevention policy may be based on source scenario rather than on probabilistic analysis. For a given area scenario method may be relevant, however, it cannot be a substitute to a global economic policy that involves public choices and, consequently, arbitrages.

In fact, a tsunami may be induced by different physical causes some of them are recurrent as for instance earthquake causes, or very hazardous for human temporality as asteroïd, etc. Every origin of tsunami may induce different probability distribution. Japanese made great improvement in the analysis of tsunami hazard from volcanic activity Acharya

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[13] E.J. Baptiste, A.M. Santomero, The Design of Private Reinsurance Contracts, Wharton Financial Institutions center, Working paper 98-32, 1998

(1989), (1990), Rikitakeand Aida (1988). Previous work was brought by Iida,Cox, and G. Pararas-Carayannis (1967) or Newhall and Self (1982),

Economist under the pressure to define a clear analysis of how risky are potential tsunamis may be induced to choice quite arbitrarily among different models and different probabilities distribution. This choice is made difficult, because assessing the probability distribution of in the field of geological analysis tsunamis is not still fully established. For instance, in a very recent contribution, Geist and Parsons (2006) aim at demonstrating how computational methods and empirical analysis can be used jointly to yield a comprehensive hazard assessment while, Loomis (2006) considers that large tsunamis waves may be described by Gumbel functions essentially, others contribution combine Weibull distribution and Poisson, etc.

The main difficulty with tsunami lies in the fact that their sources of occurrence are several. To deal with an unified view with this point we will refer to the Geist and Parsons (2006) view. The object here is to define a methodology that may induce an economist to choose scientific pre-determined probability distribution by geo-physician rather than "*ad hoc*" distributions to describe a tsunami occurrence.

Building distribution probabilities from geophysical data

Tsunami impact depends on local topography (slope), probability distribution of tsunamis with different wave heights in current location and time discount for a country. For instance, in a recent analysis of tsunamis propagation in the Ligurian Sea, Pelinovsky and ali (2001) have shown that topography of the coast may have high influence on their relative strength. However, this study is highly dependant on the historic case study of a tsunami that occurred in the end of the 19th century. Nevertheless, topography is a data to take into account in the assessment of the economic consequence of a tsunami.

Geist and Parsons (2006) consider three main sources of Tsunami: Far-field seismogenic tsunamis, Asteroid-impact tsunamis, Landslide tsunamis. Each of them has some impact on the probability distribution as it may be shown below. Geist and Parsons (2006) assume that a tsunami phenomenon follows a Poissonian arrival time process and the probability that a tsunami with amplitude h_c or greater occurring in time period T is given by the exponential function

$$P(r,T,h_c) = 1 - \exp[-\lambda(r,h_c)T]$$

where $\lambda(r,h_c)$ represents the rate or number of tsunamis per year at which wave heights are exceeded at a coastal location. r expresses both the magnitude of the source and distance between the source and site. $\lambda(r,h_c)$ may be declined according the source of tsunami.

$$\lambda(r,h_c) = \begin{cases} 10^{a+bM} & \text{(a)} \\ n(r,s) & \text{(b)} \\ \text{empiric} & \text{(c)} \end{cases}$$

Where (a) are far-field seismogenic tsunamis, and 10^{a+bM} represents the Gutemberg-Richter distribution, where M is the earthquake magnitude and *a* and *b* given parameters, for the asteroid tsunamis, $n(r,s)$ represents the annual impact rate per square meter of ocean for bodies of variable radii, and for (c), the landslides, parameters are considered as empirically distributed and highly randomly stochastic.

However, these distinction, for assessing local tsunamis are not sufficient because, a probalistic tsunami hazard analysis (PTHA) needs to take into account the nature of uncertainty. This last one may be the epistemic or aleatory. Epistemic uncertainty means that new data may decrease uncertainty, for instance, Geist and Parsons (2006) recall that higher resolution bathymetry improves the accuracy of numerical propagation computations. Hence, these improvements in knowledge could open the door to Bayesian approaches. We can augment available data in another way. Most likely, focusing on more extreme events means that we will have much less historical data available that reflects exactly the situations we are considering. This will mean developing methods to combine similar, but not identical, rare events. This is becoming established practice in the use of data from clinical trials and research to extend these Bayesian modelling methods is needed to see if they can be applied over a much broader range of situations. Bayesian methods can also be used in other ways to substitute for the lack of data by incorporating prior information and expert opinion. A large number of models are currently available for the assessment of seismic hazard. The objective in seismic hazard modeling is to obtain long term probabilities of occurrence of seismic events of specific size in a given time interval. For instance, Bayesian statistics approach is applied in the seismogenic sources of Greece and the surrounding area in order to assess seismic hazard, assuming that the earthquake occurrence follows a Poisson process.

An example of how combine economic model and geo-physical probability distribution

Let be a variable *x*(*t*) corresponding to a given index of activity (global income) on a determined coastal area. *x*(*t*) is a stochastic quantity varying in time. Following traditional methodology in analysing investment under uncertainty, see Dixit and Pyndick (1994), we can assume that *x*(*t*) follows a geometric Brownian motion. In addition, we are concerned with events like injuries and those types of event that may cause a reduction in the value of the activity by affecting dramatically the index of the variable under analysis. Thus, the continuous movement of *x*(*t*) in time will be combined when tsunami appear with down jumps. Injuries are by definition rare events and therefore a Poisson process J seems to be appropriate to model the jumps. Thus, the movement of a given activity index is a combination of a continuous component described by a geometric Brownian motion and an infrequent component described by a Poisson process

$$dx(t) = \underbrace{ax(t)dt + \sigma x(t)dz(t)}_{continuous} + \underbrace{g(x,t)dJ}_{discrete} \qquad (1)$$

where a is the rate of growth of the index; dz(t) is a Wiener process with zero mean and variance equal to dt ; and σ^2 is the variance of dx(t)/x(t) . For the discrete part, g(x,t) is a function that affects in a pre-specified manner[14] the change dx(t) over periods of time dt only if an injury occurs during that time interval, otherwise it has no effect. The jump process J is a Poisson process with rate of arrival of events $\lambda(r, h_c)$. This means that during a very small interval of time dt an event can occur with probability $\lambda(r, h_c)dt$, in which case there is a jump of size u, or the catastrophic event will not occur and the probability of this is $1 - \lambda(r, h_c)dt$. The size of the jump can be considered a deterministic known quantity or it can be considered a random quantity, in which case a probability distribution or a stochastic process needs to be specified. In addition, we will assume that the increment dJ of the Poisson process is independent of the Wiener process dz so that $E(dzdJ) = 0$.

The value of the coastal capital of the determined infrastructure under consideration will be V and corresponds to the income x(t) at time t. We assume that we are working in a finite time framework. In other words, the life of the coastal infrastructure as an investment is T. In the framework we propose, the value of the coastal capital is affected by the ongoing

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[14] For example, after the medical evaluation this can be an estimate on the number of matches that the player will miss, insurance cost, medical cost in terms of expensive treatment

position given by the index x(t) and the infrequent events incorporated in the model with a jump process. Applying the appropriate version of Ito’s Lemma gives the expected value of the change in the value function V(x,t) of the player as:

$$E[dV]=\left[\frac{\partial V}{\partial t}+ax(t)\frac{\partial V}{\partial x}+\frac{1}{2}\sigma^2x^2(t)\frac{\partial^2 V}{\partial x^2}\right]dt+E_u\left\{\lambda(r,h_c)\left[V(x+g(x,t)u,t)-V(x,t)\right]\right\}dt \qquad (2)$$

where the expectation in the right side is related (if the jump size u is considered stochastic) to the distribution of the jump size and therefore to the uncertainty in the size and not in the jump process itself. The jump part contributes a term that is significant only at points in time when injuries occur.

Viewing the infrastructure as a real asset we can advocate that the return on the coastal capital, in a risk neutral world, should be equal to the expected change in value

$$rVdt=E(dV) \qquad (3)$$

Although the risk associated with the index x(t) of such infrastructure is not directly traded in the market, it is sufficient for the calculations made in our framework to be able to identify some other asset whose risk tracks the uncertainty in x(t). A good proxy that can be used in practice is the share price of hotels, firms, and all activities link with coastal infrastructures listed on a stock exchange.

Replacing *E*(*dV*) from equation (2) into (3) and simplifying the time element we get the following partial differential equation describing our solution for the value of the infrastructure:

$$\frac{1}{2}\sigma^2x^2(t)\frac{\partial^2 V}{\partial x^2}+ax(t)\frac{\partial V}{\partial x}+\frac{\partial V}{\partial t}-rV+E_u\left\{\lambda(r,h_c)\left[V(x+g(x,t)u,t)-V(x,t)\right]\right\}=0 \qquad (4)$$

The solution of this equation with the boundary condition

$V(x,T)=\Omega(x,T)$ for all x (5)

This equation is not easy to calculate and most of the time one must resort to numerical solutions. This characteristic makes this model quite cumbersome to follow in practical terms. However, numerical solutions and increasing computational power offer a feasible solution to an important problem.

This short model shows how much the value V is dependant of the set of jumps expressed by the geophysical data.

$$\lambda(r,h_c)=\begin{cases}10^{a+bM} & \text{(a)}\\ n(r,s) & \text{(b)}\\ \text{empiric} & \text{(c)}\end{cases}$$

It is out of question, here to begin to define solutions that could be essentially “ad hoc” solutions.

5. Conclusion

This paper is an attempt to show how may be linked an interdisciplinary assessment of the impact of Tsunami between geophysical approaches and economics. It aims at showing how should be avoided preconceived ideas of what should be a tsunami from an economic viewpoint. Consequently, this paper is a cautious attempt to bring together physical data and scientific laws and economic approach is so as to build an economic assessment of coastal infrastructure under the threat of catastrophic events as Tsunami. This step is essential to assess how much financial means should be devoted to prevention. We have focused the analysis to the probabilistic part of the analysis, however, this study has to be extended to the Geographical Information System of the considered coastal area to take fully into account the potential impact of a Tsunami.

However, once the methodology is clearly expressed it may be extended to other natural hazards as floods, storms, etc. In spite of its apparently applied concerns, the whole approach is quite theoretical because it needs a reappraisal of the real option theory to the case of extreme events.

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