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## The forecast of the crises in economy and of the earthquakes in seismology. Which is the next step?

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# The forecast of the crises in economy and of the earthquakes in seismology. Which is the next step?

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## 1. Introduction.

Why a comparison of seismicity with economy.

Both have deep economic consequences. As all calamities seem to have.

Certainly the economic catastrophes have a slower pace, are often predictable and have longer effects while the others are regionally pandemic without time resolution. However adjusting the time scales appropriately one may statistically expand the similarities.

One more reason for associating the two fields is that the interest of futurologists has been recently attracted by economy and seismology with empiric, and scientific, methods and with theoretical methods and models.

In this approach I will try to ignore the literatures in both fields with the purpose to not end on a bad track. In both fields however a forecast of the type of that reached by meteorologists has not been obtained, mostly in seismology. The differences in methods of prediction between the two disciplines are great.

The first matters to make clear, also to satisfy those who a curious, are the major differences between the two fields. Let me select those which seem, at first sight, the most apparent ones.

In the economies we have a plethora of parameters describing its condition and many theories as, for instance, that of Hicks and Swank (1984). There are also of the equations conditioning the parameters from the simple Fisher eq., relating gross interest rate, to inflation and net interest, to those which govern the convergence of different types o economy to the same model (Caputo 2011).

In recent times many of these equations have been reformulated taking into account the memory of the field, or of the market, where they are applied (e.g. Caputo and Kolari 2001); this would be the rheology of the medium that is the rheology of the market or better of the people forming and acting in the market. The theories govern a plethora of parameters describing the status of the economy which are regularly monitored.

In economy there is also a continuous experimenting in *corpore vili*, mostly with success in recent times and there is no need of laboratory experiments. The prediction of the catastrophes is made with success. The governance of the economic catastrophes depends mostly on politics.

The economists would know what to do to cure the patient.

In seismology we have few parameters describing the earthquakes: the stress drop, the seismic moment, the magnitude (which is sometime affected by error because of the insufficient correction of the local ground effect due to the complexity and variety of its response), the dimension of the fault and the slip on it and also the directions of the fault. The rigorous equations relating these parameters are few, such as the Keilis Borok law (Keilis Borok 1959), and some empirical power laws such as the density distribution laws (*ddl*) of the parameters: for instance the Gutenberg-Richter and the Omori's laws and the analogous ones for the dimension of the faults and the stress drops (Caputo 1998). These parameters are regularly observed for the strong events but very seldom observed for the smaller ones where some believe is stored a relevant portion the information for prediction.

The theoretical work in seismology has made progress in the recent decades using different branches of theoretical physics. There are also empirical, mechanical and theoretical models for the statistics of the parameters and models based on statistical mechanics. Recently some relations have been extended to the foreshocks from the aftershocks sequences (eg. Sornette and Vanneste 1992). However in seismology we lack laboratory experiments although this field has been recently encouraged by the technological evolution of the instrumentation.

However, to my knowledge, until now, the improvements in the forecast was not to the point of that for the weather. A critical view backwards was useful and recommended (Keilis Borok 2008).

But a review is outside the scope of this relation, it would require much more time and the cooperation of many persons. However a comparison of the forecast in other fields could help. I selected a comparison with economy on the basis of the different approach in economy and of some elementary personal knowledge in this field..

Which then would be an indirect, humble suggestions resulting from these considerations.

Since we are moving in a fast dunkel atmosphere it would be better to measure more accurately, and for all earthquakes, all the possible measurable parameters describing their dynamic and properties such as stress drop and size of fault. Extend the measures to the foreshocks and aftershocks and set a world center for the gathering of these data and make available to the public. Foe instance here at ICTP. .

Introduce the memory, the rheology, more than in the past, in the dynamics of the preparation of earthquakes as it was done recently for the forecast of economic (but also demographic) crises. In economy the introduction of memory, which is the substitute of rheology was, although indirectly suggested by Galbraith (Galbraith 1972), explicitly stated by Demaria (Demaria 1978) in a meeting on the use of the fixed point theorem (where he stated that an economy without memory is unthinkable) and used by some economists (e.g, Teyssere and Kirman Eds. 2007) with linear and non linear but classical methods. But the explicit application of the new memory formalisms to the equations suggested for governing the economy had to wait few decades.

In finance the discussion of the dynamics of the long - run equilibrium often requires a non linear approach (Gandolfo 2002) which may ultimately be linearized in order to study the local stability. When the memory approach is used in finance it may avoid the usual non linear theories and provides a tool which allows to infer the parameters characterising the population involved in finance operations when this is subject to variation of some general conditions. It would be the case of an increase in inflation which has negative short - run but positive long - run effects on stock return, which are consistent with the well-known Fisher effect (Caputo and Di Giorgio 2006).

We should not wait longer time to use the memory in seismology since, as we will tentatively see, a seismology with memory is not unthinkable.

**2. 1 The case of contraction of Domestic Revenue Passenger Miles following the September 11, 2001 terrorist attack in New York.**

The first analytic example of memory effect in economy is that concerning the contraction of domestic RPM (Revenue Passenger Miles) (one paying passenger flown one mile) following the 11 September, 2001 terrorist attack to the twin towers of New York which has been thoroughly studied by several authors (e.g. Block et al. 2006, Ito and Lee 2005) who also studied the impact on driving fatalities (e.g. Block et al. 2005). The methods of analysis were generally those of SVAR obtaining good results also on the forecast of the future developments of the crisis. The authors found that after the decline there is no evidence that the number of RPM as of the end of 2003, has reached the level which it would have in absence of the crisis.

In simple cases economic dynamics may be described by assuming that output increases over time as a response to excess demand in the goods market, that is (Caputo and Di Giorgio 2006):

$$DY(t) = k - br(t) - cY(t) \qquad (1)$$

where *r(t)* represents a perturbation, *Y* is the response of the market, *k* and *c* are parameters to ensure stability and convergence and *D* means derivative.

We assume here that *Y* is the RPM and that it varies over time as a response to the excess (or lack of) demand in the market. The perturbation of the 11 September, 2001 terrorist attack is represented by *r(t)*.

The effects of *memory* is introduced in this simple model by replacing equation (1) with

$$DY(t) = k - br(t) - dD^{(v)} r(t) - cY \qquad (2)$$

where $D^{(v)}$ is the operator

$$D^{v} f(t) = (1/(\Gamma(1-v)))\int_{0}^{t} (df(\tau)/d\tau)d\tau/(t-\tau)^{v} \qquad (3)$$

called, perhaps improperly, fractional derivative of order $v \in [0,1[$ which has been thoroughly studied by several authors (e.g. Podlubny 1999, Diethelm 2010). The fractional derivative is a frequently used tool in applied science and has been applied in many field such as theoretical physics, biology, medicine, chaotic dynamics, diffusion, chemistry, plasmas in bounded domains, geophysics and in plasma turbulence.

After the shock the conditions of the market have first a sudden change which however slowly return to the previous condition when the memory of the shock fades away. The old trend returns and, later, also the first sudden change, more slowly, will be recovered.

In figure 1 we show the monthly RPM in the U.S. after the terrorist attack of September 11, 2002. The monthly data are averages over 12 months to remove the large seasonal effects.

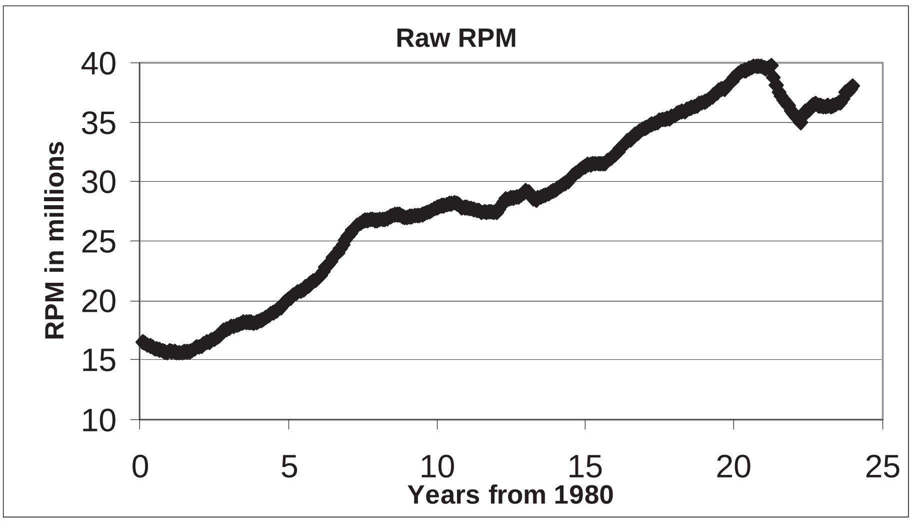


Figure 1. Monthly RPM in the U.S. after the terrorist attack of September 11, 2002. The initial year is 1980. The monthly data are averages over 12 months to remove the seasonal effects.

In figure 2 we show the data of figure 1 after removing the apparent linear trend from 1994 through 2000. The data show clearly the effect of the shock received by the market on September 2001. Our scope is now to model the effect of the shock represented by the decay and the recovery with an apparent stabilization.

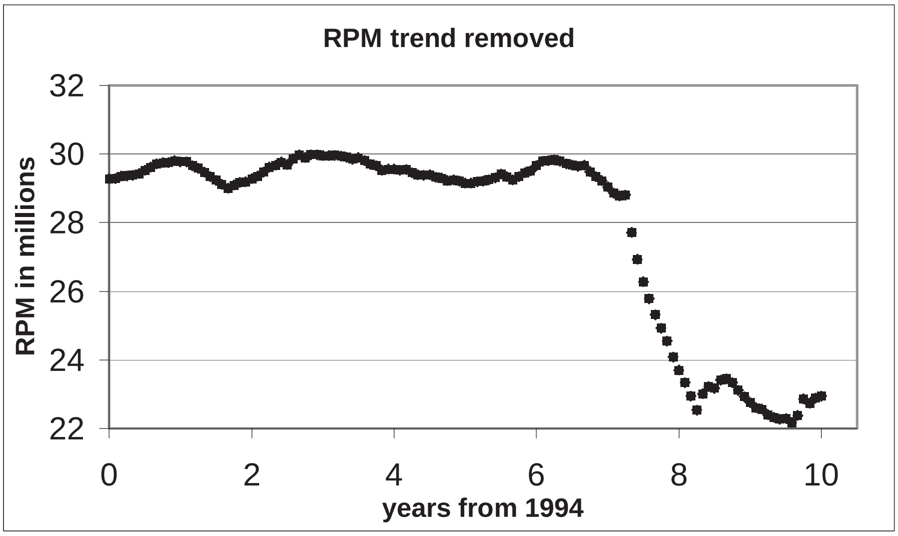


Figure 2. In the ordinate is the monthly RPM in the U.S., shown in figure 1, after removing the trend from 1994 through 2000. Note the first relevant hump after the decrease and the possible second hump after the first.

In order to simulate the effect of the shock on the number of RPM caused by the attack of September 11, 2001 we assume that *r* is represented by a step function of amplitude *b* affecting the system represented by *Y*. The fear spreads in time and eventually vanishes.

The values of the three parameters defining the fitting of the effect of the perturbation shown in figure 3 are $c = 3$, $v = 0.1$, $b = 0$ and $d = 2.2$, and the origin of time is assumed at the beginning of the perturbation, the result of the fitting is shown in figure 3.

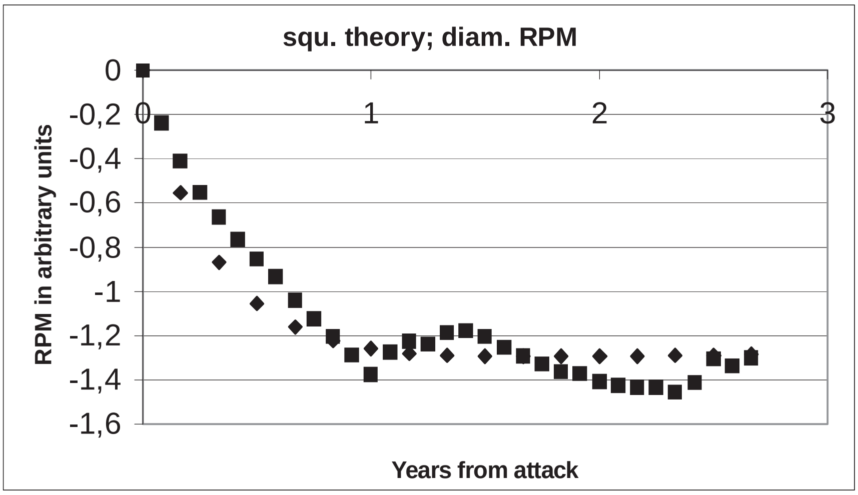


Figure 3. In the ordinate is the monthly RPM in the U.S. after the terrorist attack of September 11, 2001, in arbitrary units after subtracting the initial value. In abscissa the years are counted from the beginning of the perturbation. The monthly data are averages over 12 months to remove the seasonal effects. Squares are the observed RMP, the diamonds represent the values estimated in theoretical modelling.

**2.2 The case of the 1951 Po river flood.**

In 1951 the Po river in North Italy flooded a vast area of Polesine. The inhabitants fled the area and found shelter in the neighbouring regions. About 185.000 people left the area affected by the flood. After the water left many people came back to their homes or places. However relevant percentage did not come back to their old dwellings. In the following figure 3a we see the census of the population in the years fro 1871 through 2001. The trend is very remarkably similar to that of the figure 3 for the RMP after the 2001 September 11$^{th}$ attack to the twin towers. We particularly note the lack of recovery in the return to the previous situation. A possible fit with a theoretical curve would allow to compare parametrically the behaviour of the two population after sudden catastrophes of different type.

The figure 3a indicates also a possible oscillation in the number of people returning to their old dwellings as the eigenoscillation of a physical system; to prove it, however, data with higher resolution, which is not available in this case, would be needed.

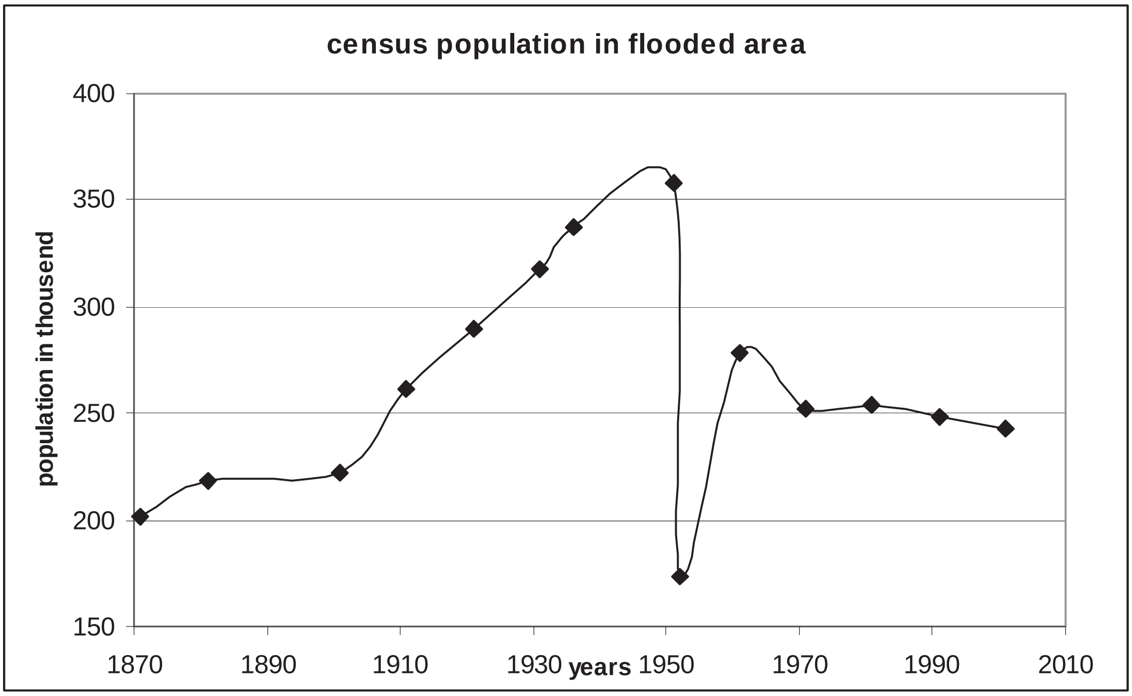


Figure 3a. Census of the population in the region Polesine (North Italy) after the 1951 flood caused by the Po river. We note the lack of recovery to return to the previous situation as it is noted for the RPM shown in figure 3.

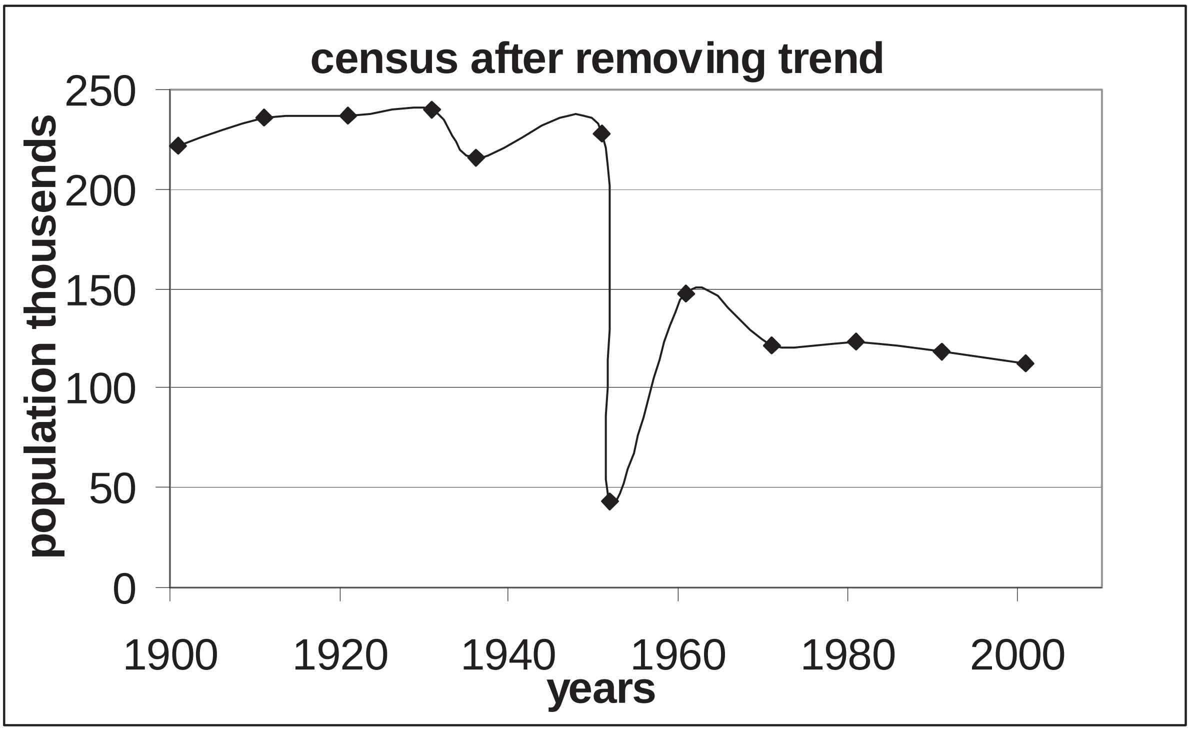


Figure 3b. Census of the population in the region Polesine (North Italy) after the 1951 flood caused by the Po river obtained removing the linear trend of increase of population between 2001 and 1951. We note the lack of recovery to return to the previous situation as it is noted for the RPM shown in figure 3. We also note the first humps in 1960 and the possible one in 1981 which are similar to those noted in figure 2 for the RPM.

The figure 3b shows the data after removal of the trend between 2001 and 1951. The decrease signalled by the datum in 1936 of figure 3b, indicates a migration to new fertile land made available in Central Italy.

The high correlation between the data of figure 2 and those of figure 3b is obvious.

**2.3. Conclusions from the analysis of the reduction of the number of passengers after the terrorist attack.**

In general the relaxation time is represented by a single parameter, but in many memory applications it is represented by two parameters; in our case $1/c = 1/3$ and $v = 0.1$ which are not allowing a intuitive and direct comparison with the classic cases when one single parameter is used. However the use of the classic form of equation (1) ($d = 0$) would not allow an acceptable fitting to the data, an extension to the case which includes memory seems a plausible way. The memory equation used in this study, when a sufficiently long time series after the shock is available allows the tentative estimate of the relaxation time of the market. One more feature of the simple equations, as equation (2), is that comparing the values of the limited number of parameters defining it and resulting from the analysis of sets of data representing different phenomena allows to compare the characteristic properties of the different systems or phenomena or markets. As would be the case when modelling the effect of the 1951 flood of Polesine on the people living in the region using the same method used for the RPM data after the September 11 attack to the twin tower in New York city.

**2.4. The effect of the memory on the Gross Domestic Product when the prime rate is subject to a step variation.**

Asymptotically the output is always reduced by the same factor, however the path of dynamic adjustment differs considerably from the case without memory. In particular a hump-shaped response of output is observed when the memory coefficient is large enough, with output declining in the medium run more than in the new steady state equilibrium.

This is somehow coherent with the idea that a monetary policy *shock* or *surprise* has a temporary negative effect on output, as implied by the impulse responses of standard VAR models. In our setting the monetary policy contraction is permanent, hence there is a permanent negative effect on output which is reached gradually. The effect of memory is to induce a temporary non-linear response of output that is added to the monotonic output dynamics obtained in the standard model. The temporary nature of the effect is due to the fact that past values of the prime rate loose their informative content as time goes by.

The results obtained in this section are qualitative; quantitative and realistic results may be obtained when estimated values of the parameters will be available. It is to be noted that increasing the parameter *u*, the order of fractional differentiation, implies a smaller initial hump and a more rapid relaxation That is the larger values of *u* imply a more rapid, more time limited and smaller amplitude of the effect of the memory. This confirm the results obtained by Caputo and Di Giorgio (Caputo and Di Giorgio 2006).

**2.5. Reaction of the GDP when the prime rate is subject to 2 successive steps of equal amplitude.**

We shall see now the effect on the GDP caused by a two successive steps of equal amplitude at the times $t_0$ and $t_1$ respectively, the effect of the memory is a broad pulse followed by another pulse with larger amplitude as seen in figure 4.

When $t_1$ - $t_0$ is sufficiently large the effect of the two pulses are practically independent. The effect of the memory may last for a relatively long time depending on the order of the relaxations time of the memory namely when the order of fractional derivative is small.

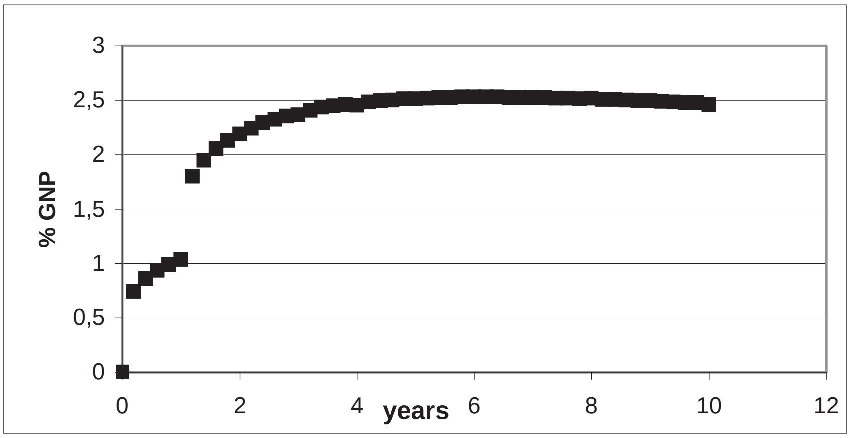


Figure 4. Effect of two successive steps of equal amplitude separated by one year. The first step is set at the origin of time.

It is of interest to compare the effect of two successive steps of equal amplitude with that of a single step with amplitude sum of those of the two. The comparison is shown in the figure 4 with the difference of the two effects where we used the same parameter values used for figure 5.

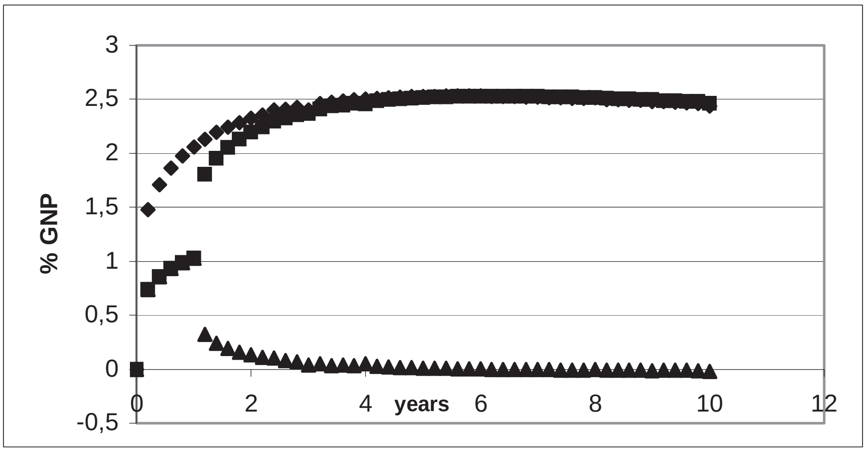

Figure 5. Comparison of the effects of two successive steps of equal amplitude (squares) with that of a single step with amplitude sum of those of the two (diamonds). The time is measured in units of the relaxation time $1/c$. The difference is given by the curve defined by the triangles. It is verified that in the short range the effect of the single step is obviously larger while in the long run is larger the effect of the two successive steps.

The asymptotic value is as in the case of absence of memory; we note then that the effect of the memory due to the two steps of equal amplitude is asymptotically nil as that due to a single step.

It is clear and obvious that the single step with double amplitude has larger effect in the short range, however the case of monetary contraction in 2 steps allows to test the reaction of the system and one would reach almost the same effect in the long range. This advantage would increase when using more than 2 smaller steps.

**2.6 Reaction of the GDP when the prime rate is subject to two steps variation with opposite sign and equal amount. The irreversibility of the effect of the memory.**

In case the reaction of the system to the first contractionary monetary policy does not result as required and it is needed to go back to the previous monetary condition, a step with sign opposite to that of the first and the same amplitude may be considered.

In the case when a second step, with the same amplitude and opposite sign of the first, is applied to the prime rate at the time $t_1$, the effect of the second step is superimposed to the tail of the first is shown in the figures and the solution now is

We have chosen values of the parameters defining the curves different from those used by Caputo and Di Giorgio (2006) in order to give more evidence to the effect of the separation time of the two steps.

The asymptotic value again is asymptotically nil.

When $t_0 << t_1$ and the relaxation time is short is sufficiently short the effect of the second step is independent of the memory effect of the first one. The total affect is near the sum of the two when $t_1 - t_0$ is relatively small; when $t_1 - t_0$ is increasing then the effect of the second is increasingly independent of the effect of the first one.

We may then expect from the second step an effect on the GDP equal, but with opposite sign, of that caused by the first one, which confirms that the effect of the sum of small steps of the prime rate is not equal to the effect of the sum of the steps.

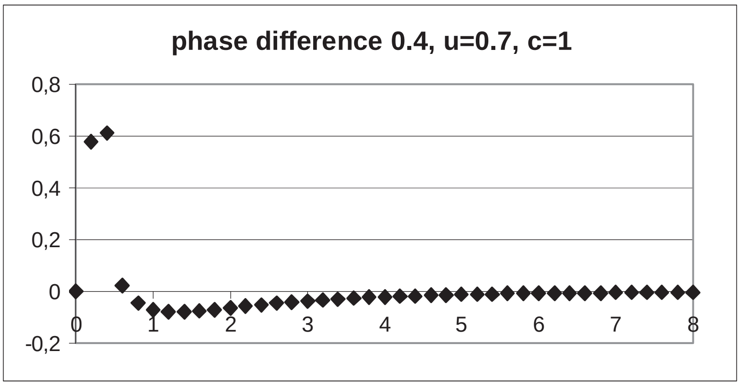


Figure 6. Memory effect caused by two successive step with the same amplitude but opposite sign separated by one 0.4 units of time with *u* = 0.7, *c* =1, where the time is measured in units of relaxation time 1/*c*. In this case the memory effect of the first step diminishes almost totally that of the second. The total effect is almost nil after the second step, its minimum is – 0.09; its theoretical value, if it were independent of the first, would be as that of the effect of the first step but negative that is about - 0.6. Note that the signal begins with the zero value for *t* = 0. The ordinate is in units of *sd*.

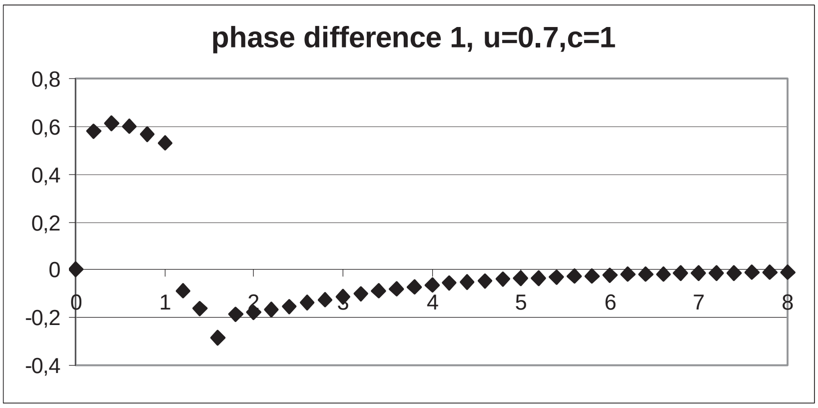


Figure 7. Memory effect caused by two successive step with the same amplitude but opposite sign separated by one unit of time with *u* = 0.7, *c* =1, where the time is measured in units of relaxation time 1/*c*. The memory effect of the first step diminishes by 60% that of the second. The minimum of the total effect is - 0.29; its theoretical value, if it were independent of the first, would be as that of the first but negative that is about - 0.6. Note that the signal begins with the zero value for *t* = 0. The ordinate is in units of *sd*.

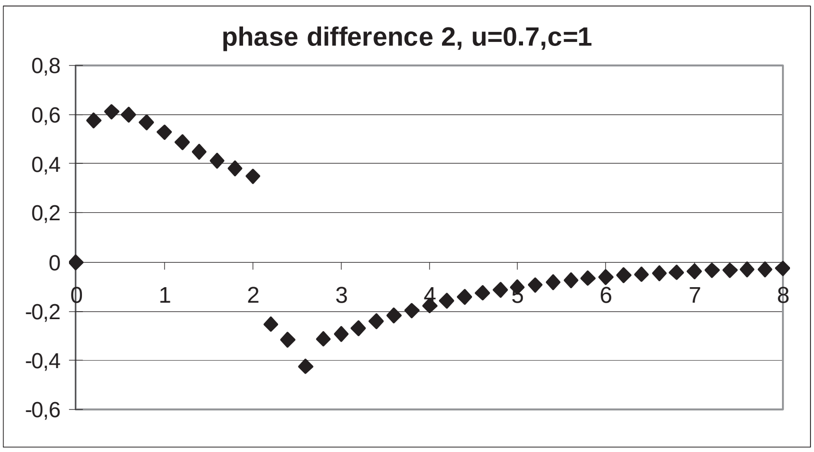


Figure 8. Memory effect caused by two successive step with the same amplitude but opposite sign separated by two units of time with *u* = 0.7, *c* =1, where the time is measured

in units of relaxation time 1/*c*. The memory effect of the first step diminishes the maximum effect of the second by 40% .The minimum of the total effect is – 0. 43; its theoretical value, if it were independent of the first, would be as that of the first but negative that is about - 0.6. Note that the signal begins with the zero value for $t = 0$. The ordinate is in units of *sd*.

We first note that the time needed for the total relaxation of the effect due to the memory after the second step, as well as the amplitude of the minimum effects due to this step are increasing with the separation of the two steps. Numerically, when $u = 0.7$ and the time separation between the two steps is one time unit, the time required to reduce the negative effect after the second step to 50 % of its minimum is 0.8 time units. The time required to reduce the negative effect after the second step is 1 time unit when the separation between the two steps is 2 units of time. The numerical evaluations are estimated for $u = 0.7$ and for the parameter values given in the captions of the figures.

A more detailed analysis concerning the effect of the order of fractional differentiation *u* in the range [0,1[ shows that decreasing the value of *u* causes an increase of the time required to reduce to 50% the negative value after the second step. The time to minimum value decreases with increasing *u*.

In conclusion the most important memory phenomena caused by two successive step variations of *r* with the same amplitude but opposite sign are the time duration to recover the initial condition and the minimum negative effect after the second step: both increase with the time separation of the two steps.

It is thus clear that in order to avoid negative affects on the GDP, the second corrective step should be applied as soon as possible.

The effects caused by the non memory terms is increasing steadily to an asymptotic value while that of the memory is fading to zero.

**2.7. Conclusion on the effect of memory in economy..**

Asymptotically the output is always reduced by the same factor, however the path of dynamic adjustment differs considerably from the case without memory. In particular a hump-shaped response of output is observed when the memory coefficient is large enough, with output declining in the medium run more than in the new steady state equilibrium. This is somehow coherent with the idea that a monetary policy *shock* or *surprise* has a temporary negative effect on output, as implied by the impulse responses of standard VAR models. In our setting the monetary policy contraction is permanent, hence there is a permanent negative effect on output which is reached gradually. The effect of memory is to induce a temporary non-linear response of output that is added to the monotonic output dynamics obtained in the standard model. The temporary nature of the effect is due to the fact that past values of the prime rate loose their informative content as time goes by.

We note also that the economic phenomena withy memory are irreversible and therefore, after an economic crisis is impossible to return to the previous condition and a new trend is generated.

**3. The phenomena in Seismology. The estimate of the regional stress field.**

Economy has borrowed from seismology the term *stress* which, in pragmatic terms, is used to express the condition of a market which does not allow money to circulate fast.
As an example when the price of houses is too high for the income of normal peoples the pertinent market is under *stress*. Then when this condition is verified the government supposedly ruling the economy is in alarm.

In seismology we have the same terminology with the difference that the measure of the stress in the crust is tentatively estimated by observing displacements of the surface with various methods. However the spaces covered by this monitoring is limited or the monitoring is made with insufficient resolution. If the monitoring were made with sufficient extension and resolution an estimate of the stress condition in the crust would be possible and risk estimated but rarely taking into account the relaxation occurring during the accumulations of the stress.

A tentative example is that for the San Andreas fault where it was assumed the displacement between the sides of the fault on the surface is 5 cm/yr as measured with ground observations and space techniques. Modelling the cumulative distributions of the local earthquakes with known seismic moment and also the associated accumulated slip along the fault is estimated that, in 1987, a cumulative displacement of at least 170 cm had not been released since the 1906 San Francisco earthquake. As a consequence an earthquake with $M_0 = 10^{28.4}$ was possible.

The stress accumulated in the period 1906-1987 ha been estimated using the accepted average displacement of 5 cm/yr on the San Andreas fault however the corresponding stress has been reduced taking into account the rheological relaxation estimated with a model resulting from the observation of the anelastic dissipation of seismic waves. The model used for the relaxation is based on the simple inclusion of a memory formalism in the stress strain relations as it is done in economy for the effect of the changes of the prime rate on the Gross Domestic Product.

The memory model obtained introducing a fractional derivative of order z in the stress strain relation (Körnig and Müller 1989, Caputo 1987) gives the following relaxation of the stress $\sigma$

$$\sigma = \varepsilon\tau\mu(((\sin(\pi z))/(\pi z))\int_0^\infty (1-\exp(-u^{1(z}t/\tau))du/((u^{1/z}/\tau)(u^2+2u\cos\pi z+1))$$

$$\tau = (\eta/\mu)^{1/z}$$

while the classic Maxwell model gives

$$\sigma = \varepsilon\tau\mu(1-\exp(-ut/\tau))$$

In the figure is shown how the stress increases as function of time for a constant strain for various memories defined by the order of fractional derivative**.** The ordinate the stress is in units of $\tau\mu\varepsilon$ ($\tau = 10^{10}$s = relaxation time, $\mu = 3\ 10^{11}$ gr cm$^{-1}$ s$^{-2}$ = rigidity of the medium, $\varepsilon = 10^{-13}\ s^{-1}$ = strain rate), $z = 0.6$; the time in abscissa is in units of the relaxation time.

With the assumed relaxation time $\tau = 10^{10}$s (about 300 years) (Caputo 1993) for $0 < t < 0.05\ \tau$ the stress increases linearly with slope 0.4.after the relaxation time is elapsed and we find a stress 0.568 $\tau\mu\varepsilon$ where $\tau\mu\varepsilon$ is the stress which would have accumulated without memory that is in absence of relaxation.

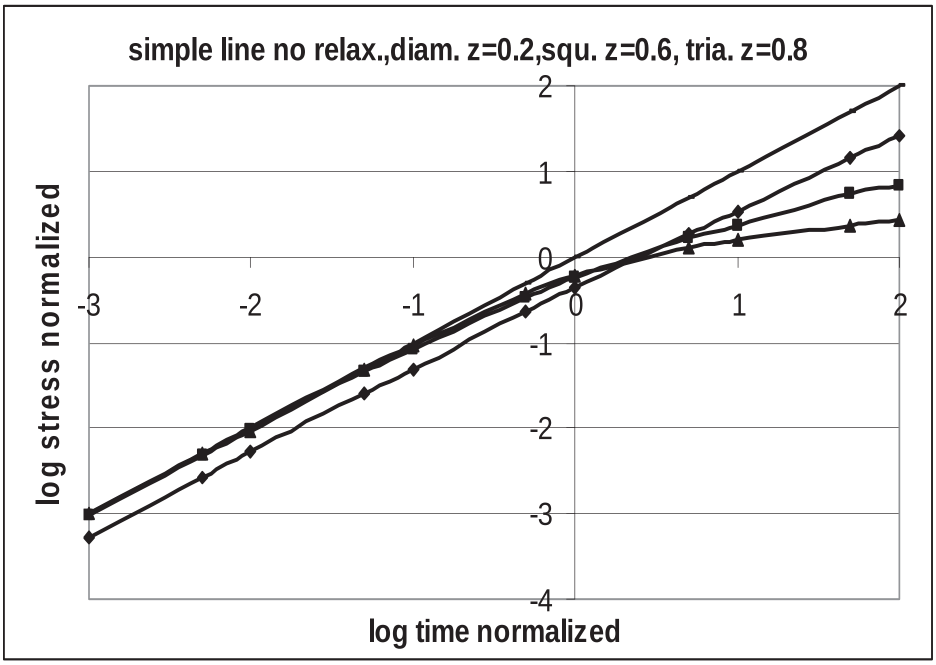


Figure 9. The figure shows how the stress relaxes as function of time for a constant strain and for various memories defined by the order of fractional derivative *z*. In the ordinate the stress is in units of $\tau\mu\varepsilon$ ($\tau$ = $10^{10}$s = relaxation time, $\mu$ = 3 $10^{11}$ gr $cm^{-1}$ $s^{-2}$ = rigidity of the medium, $\varepsilon$ = $10^{-13}$ $s^{-1}$ = strain rate), the time in abscissa is in units of the relaxation time.

We note that at times almost two orders of magnitude larger than that the relaxation time, when z = 0.8, the stress has reached almost complete relaxation; and is almost two orders of magnitude smaller than in the case of absence of relaxation.

A serious problem arises concerning the initial time of the perturbation of the elastic field which could let us know which could be the actual rate of growth of the stress.

One more problem is that the longer relaxation time implies that increases the probability that other perturbations occur to alter a simple course of phenomena.

All the preceding considerations concern homogeneous elastic bodies, for fractured bodies the relaxation may be much faster.

One may then draw the diverging curves used in climatology for predicting the future temperature of the atmosphere.

This is not yet a solution, using different words it could just be seed.

Concerning economy we know a plethora of parameters monitoring it in real time, or the time becomes real when we know the values of the parameters, and we still have the crises; but very often this is due to the very simple fact that we spend more that we earn and live above our means. There is no prescription for this disease. Rightly the crisis comes, there would not be justice otherwise.

I could have selected other examples among the few available in the literature, those selected were easier for me to find without asking permissions to reproduce the figures..

Concerning economy we know a plethora of parameters monitoring it in real time, or the time becomes real when we know the values of the parameters, but we still have the crises. Very often this is due to the very simple fact that we spend more that we earn and we live above our means. There is no prescription for this disease. Rightly the crisis comes, there would not be justice otherwise.

### 4.1 The phenomena in Seismology. A laboratory experiment.

The first very relevant difference with the economic phenomena is obvious: in economy most phenomena occur under the eyes of all and often they are known in real time and are described by a plethora of parameters. In seismology, instead, we are dominated by the Fernwirkungsgesets since all happens in the Lithosphere. we have only indirect information on it and the description of it is made with few parameters. However contrary to economy we ca make laboratory experiments, for instance on the fracture of rocks. Let me describe a very simple and perhaps rudimental laboratory research on the squeezing of rocks which was made in order to study the electromagnetic field emitted by rock when squeezed.

To this purpose a wide band antenna was used to sound the electric component of the EME radiation in the ELF and VLF, precisely in the Band [0.8,12] kHz..

It is important to note that during the above-mentioned laboratory experiments the EME had been monitored at the same time of the acoustic one.

### 4.2 Laboratory experiments on the EME emission from rocks subject to pressure.

Rock samples with diversified dimensions and lythologies have been subject to uniaxial compression almost linearly increasing to fractured. The experiments have been made with samples surrounded by air or fresh or salty water, with boundary conditions free of confining pressure and at about 20°C temperature. During the compression we observed impulsive EME (fig.10) occurring with two different modes: orderly impulsive sequences (OIS) and disorderly impulsive sequences (DIS).

The OIS is characterised by high frequency micro-impulses, which follow one another at regular intervals (fig.10a). In the spectrogram (fig.10b) they give a uniform band centred in the average frequency of the impulses. The variability of the period of the width or of the impulses sets this frequency at about 3 kHz. The regular repetition of the sequences determines the uniformity of the phenomena. Assuming unity the time $T_1$ necessary to bring the sample to fracture with linearly increasing stress, the OIS occurs at $T_{0.5} = 0.5\ T_1$.

The DIS has the characteristic to begin at around $T_{0.5}$ and culminates at the time of fracture (fig.10a). It is a wavelet with spectrum formed by harmonic components of the central peak of the wavelet, which has larger amplitude, but with small interferences caused by side lobes. In general the width of the wavelet are much larger than in the OIS. The impulses are distributed in various manners and with attitude to cluster. Comparing the EME with the acoustic ones we note that to each EME signal, or set of signals, corresponds to a mechanical one associated to micro-fractures (fig.10c). However the inverse is not verified.

Near the time of fracture the clusters are more numerous and produce a maximum density and intensity with a peak at the time of the fracture.

Of the 42 rock samples examined, 36 showed EM emissions. The 6 samples which did not show EM emissions concern cases of unsuccessful modes of experimenting due, for instance, to poor parallelism of the sides of the samples of the plates of the press which caused anomalous fracturing of the samples. The 36 samples gave the emission of DIS and 18 of them gave also the OIS, however due to the weakness of the signals there is possibility that the OIS could not have been revealed by our instrumentation as in the case of the other samples. All the 14 different lythologies examined (massive limestone, clay sandstone, metamorphic rocks and also concrete) showed EME.

The difference in the reactivity of the samples seems to be due to their difference in mechanical properties, that is type of deformation and /or structural homogeneity more than mineralogical composition even if the latter may somewhat condition the first two.

The granite samples which contain quartz in form of phenochrystals showed a reactivity which was god but not exceptional, comparable to that of a massive limestone sufficiently rigid and not homogeneous. In reality also this is related to the fracturing of the material since those fragile and with particular structural inhomogeneity, as porphyry, have a larger number of point of nucleation for the micro-fractures and show diffuse fracturing during the compression which is followed by an increased reactivity from the point of view of

EME. To the other side are the samples that are structurally isotropic and homogeneous and have quasi-plastic deformation, such as the clay sandstone; under pressure these deform plastically producing a limited number of micro-fractures and finally fracture in a single shock.

In these case the EME have the same general quality of the other types of rocks but the emission is rather scanty and limited to the final cluster.

We may then conclude that the fracturing plays a fundamental role in the EME whatever this mechanism may be. In order to explores the physical properties of this mechanism we made some experiments with saturated samples immersed in fluids during compression and fracture. The saturated samples immersed in fresh water reduces the number of OIS while saturation with salty water (200 g/l) almost cancelled these emissions except at the final cluster when appear monochromatic impulses with frequency centred around 2.4 kHz (fig.10b).

Concerning the OIS it seems that their presence be not influenced by water in spite of their lower intensity relative to that of DIS. Further experiments relative to the attenuation of EM impulsive signals artificially generated verified that the effects of saturating water, salty and fresh, occurred according to the theoretical expectations.

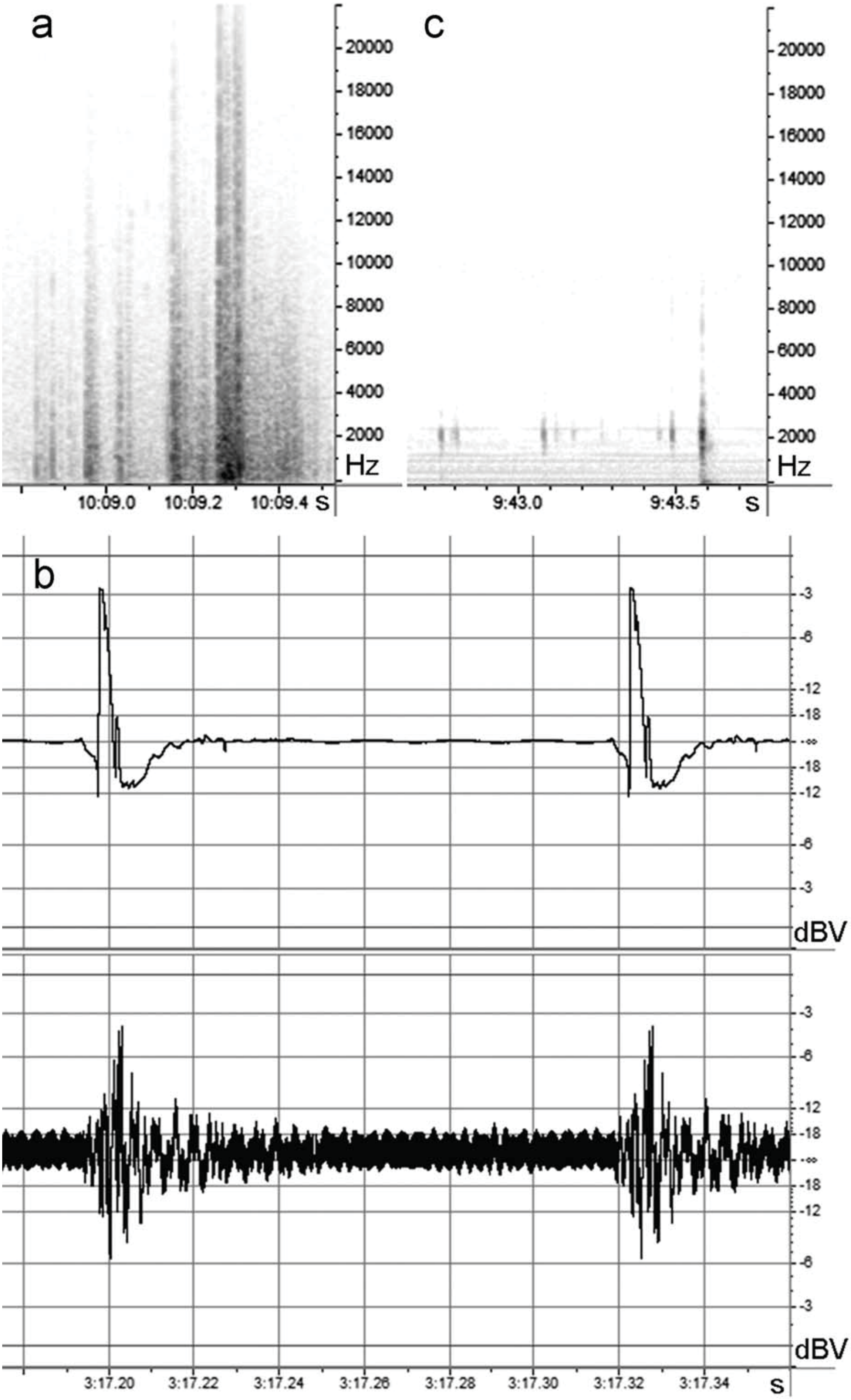
a
c
b
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Hz
10:09.0
10:09.2
10:09.4
s
9:43.0
9:43.5
-3
-6
-12
-18
-∞
dBV
3:17.20
3:17.22
3:17.24
3:17.26
3:17.28
3:17.30
3:17.32
3:17.34

Fig. 10. Properties of the disorderly impulsive sequence (DIS). This emission of DIS is formed by impulses with variable width (which however, is always larger than in the OIS) and disorderly distributed in time but with attitude to cluster. In (10a) we note that these impulses concentrate at the time of fracture (R) when we see the highest peak, the amplitude of the corresponding spectra have a decreasing content in the high frequencies. In (10b) we note that to every EME corresponds an acoustic signal, or presumably a micro fracture, shown below. When the sample was saturated and immersed in salt water the OIS are not attenuated, while the DIS almost disappears, but in (c) we note the monochromatic emissions in place of the strong impulses appearing near the fracture, as is clear in the comparison of (a) with (c).In abscissa is the time measured in minutes and seconds with tenths of seconds. In the ordinate is the frequency for (a) and (c), while in (b) it is the amplitude. The intensity of the spectra (a) and (c) is indicated by the intensity of grey.

### 4.3 Field observations of EME.

The extractive activity in a quarry of massive limestone allowed monitoring the emission of EM emissions when rocks are subject to an extensive stress and also in a scale which is not possible in the laboratory. The extraction is made with exploding a line of charges aligned with the front of the rock that, after the explosion of the charges, relaxes behind the line of the explosions following the compression. The extensional stress induces extensional micro fracturing which take the rock mass to a new elastic equilibrium. We recorded EME during 8 explosions at the quarry and in all, during and after the explosions, observed impulsive sequences of EME with the same characteristics.

In the sequences we may recognise two principal episodes. The first is formed by set of impulses at regular intervals; the latter is formed by a set of stronger impulses chaotically distributed. We may then put forward the hypothesis that also in extensional fracturing there is EM emissions analogous to those recorded in the laboratory.

### 4.4 Conclusions on the EME emission.

The experimental observations seem to connect the EME to the fracturing of the rocks and to the possible presence of fluids saturating the pores, which would correspond to the phenomenon of dilatancy well known in seismology. A physical explanation on how the EM emission may be generated by rock being fractured has not yet been found although many hypotheses have been put forward mostly to explain the precursors of earthquakes of electromagnetic nature.

The EME possibly caused by fracturing may also be used to monitor the stress conditions of rocks for geological or engineering purposes and also as an earthquake precursor.

We used 3 VLF stations to monitor in the atmosphere the EME hopefully preceding earthquakes and of the type observed in the cave and in the laboratory. From August 03.2003 through September 05.2005 we recorded only 3 EME of the type of the OIS and occurred from 3.7 to 4.4 days before the earthquakes with magnitude larger than 4.5 occurred at distances less than 300 km from the recording station. EME signals of different type but occurred at analogous times and distances separations and an analogous threshold of magnitude, have been observed also by Asada [5], Liu [6] and by Pulinets [7] and considered by the authors possible precursors.

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