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A statistical measure of financial crises magnitude

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HIGHLIGHTS

- We propose a new statistical measure of financial crises magnitude.
- The crash magnitude is computed by analogy with the earthquakes Richter scale.
- For the US market, we establish the magnitude and the hierarchy of financial crises.
- Statistical pattern of a financial crisis is described by Pareto and Wakeby distributions.
- We obtain a financial Gutenberg–Richter relation.

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ABSTRACT

This paper postulates the concept of financial market energy and provides a statistical measure of the financial market crisis magnitude based on an analogy between earthquakes and market crises. The financial energy released by the market is expressed in terms of trading volume and stock market index returns. A financial "earthquake" occurs if the financial energy released by the market exceeds the estimated threshold of market energy called critical energy. Similar to the Richter scale which is used in seismology in order to measure the magnitude of an earthquake, we propose a financial Gutenberg–Richter relation in order to capture the crisis magnitude and we show that the statistical pattern of the financial market crash is given by two statistical regimes, namely Pareto and Wakeby distributions.

1. Introduction

As pointed out in Mishkin [1], the financial crisis is defined as a financial market disruption due to asymmetrical information. The adverse selection and the moral hazard block the funding channels of productive investments opportunities leading to a financial market breakdown. Other authors, such as Kindleberger and Aliber [2], define the financial crisis as a sharp decline of assets prices (i.e. a market crash) in combination to the failure of financial and nonfinancial firms, deflation or disinflation, or disruptions in foreign exchange markets.

Nevertheless, the features of a financial crisis or financial crash are not very clearly defined. What means a sharp decline in assets prices? It is not obvious whether the "second Black Monday" on October 27, 1997 should be considered a US market crash given that the stock index decreased by 7% in one day and recovered quickly. Should the collapse of prices be called a financial crash only in Asia, where the stock index lost about 24% in one day? In other words, at what critical point the financial market is to be considered a crashed market? On the other hand, even though the shocks or the turbulences lead to a market collapse, it is difficult to assess how deep the financial crash is. In order to answer these questions, it is necessary to introduce a new quantitative measure for these events.

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This paper proposes a statistical measure of financial crises through an analogy between the earthquakes and the financial market crises. Both in seismology and in finance, these phenomena are relatively rare. The basic idea is that these extreme events are related to the critical points of the energy released by the earth or by the financial market. In geophysics, the advantage is that the beginning and the end of an earthquake are clearly identified by simple empirical observation while, in finance, it is not always possible to identify precisely by simple empirical observation the moment when a crash begins and ends. Therefore, it is necessary to develop two quantitative measures, one for the magnitude of the crash and another for the detection of the beginning and the end of the crash.

In seismology, the magnitude of an earthquake is determined with the Richter scale. This famous scale is defined by the logarithm of the total energy released during an earthquake, E_{tot}. It is widely agreed that the seismic energy released by an earthquake is related to the earthquake's magnitude M by the Gutenberg–Richter relation [3,4]:

$$\ln E_{\text{tot}} = a + bM. \tag{1}$$

Parameter a indicates the existence of the threshold energy, $E_0 = \mathrm{e}^a$, which corresponds to $M = 0$. The above relation can be rewritten as

$$\frac{E_{\text{tot}}}{E_0} = \mathrm{e}^{bM} \iff M = \frac{1}{b} \ln \left(\frac{E_{\text{tot}}}{E_0} \right). \tag{2}$$

The seismic energy follows a power law probability distribution[1]

$$P\left(E_{\text{tot}}\right) \sim \left(\frac{E_0}{E_{\text{tot}}} \right)^k \tag{3}$$

where k is the power law distribution parameter. Taking into consideration the probability distribution of the total energy released by an earthquake, the magnitude of the earthquake on the Richter scale is defined by

$$M \simeq \frac{1}{k} \ln \left(\frac{1}{P\left(E_{\text{tot}}\right)} \right). \tag{4}$$

Under this form, the magnitude of an earthquake on the Richter scale is the logarithm of the inverse frequency of the earthquake.

The analogy between earthquakes and financial market crises can be observed in terms of probability distribution. Mandelbrot [5] shows that the probability of large price changes decreases as slow as a power law due to the fat-tailed return distribution. Consequently, the probability distribution of earthquakes is similar to the probability distribution of large price changes.

In finance, the first measure of the financial crises magnitude was proposed by Zumbach, Dacorogna, Olsen, and Olsen [6]. Analogous to the Richter scale, they constructed a Scale of Market Shocks (SMS) in order to measure the foreign exchange market shocks [7]. Based on an analogy with mechanics, this indicator is constructed assuming that the market releases a kinetic energy measured by the price variance. Moreover, the variance is assumed to follow a log-normal distribution. Using a kernel approach in order to compute an aggregate volatility, the SMS indicator is defined as integral of a function that maps volatilities over time scales.

Another measure is proposed by Maillet and Michel [8]. They constructed an indicator called Index of Market Shocks (IMS). The kinetic energy released by the market is assumed to be the price volatility. The IMS indicator is directly obtained from the Richter scale formula. They assume that the logarithm of the price volatility follows a normal probability distribution. Unlike Zumbach et al. [6], Maillet and Michel [8] proposed a measure that uses only data belonging to the period under measurement without overlapping between consecutive measures.

Other studies discovered similarities between the financial market crashes and the earthquakes. Bouchaud, Sornette and Johansen [9] show that the financial crashes can be characterized by precursors and replicas like earthquakes. In fact, they state that the stock market is an example of a self-organized system. Johansen and Sornette [10,11] and Johansen, Ledoit and Sornette [12] show that the largest financial crashes are not necessary related to the existence of a fat tail in the distribution of the stock market prices. Moreover, they indicate that the financial crashes are outliers. This conclusion is based on the investigation of the number of drawdowns' probability distribution (i.e. the cumulative loss from the last local maximum to the next local minimum). The basic idea is that a complex dynamic system such as the financial market can go through a so-called critical point, defined as an explosion to infinity of a normally behaving quantity. In natural sciences, the hallmark of criticality is the power law, namely the system goes to infinity according to a power law [13].

Other authors analyze the financial turbulences through the dynamic of assets' volatility or return [14,15]. Kapopoulos and Siokis [16] use the Gutenberg–Richter relation (1) in order to state a financial Gutenberg–Richter rule for aftershocks. They show that the aftershocks obey this rule. Lillo and Mantegna [17] and Selçuk and Gençay [18,19] show that, after a financial crash, the aftershocks in the market follow a power law, analogous to Omori's law. Mu and Zhou [20] investigate the decay behavior of the volatilities after large shocks for different thresholds.

1 The Gutenberg–Richter law shows that $P\left(E_{\text{tot}}\right) \sim E_{\text{tot}}^{-1.5}$.