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A quantile-based Time at Risk: A new approach for assessing risk in financial markets

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HIGHLIGHTS

- We provide a new measure for assessing the risk in financial markets.
- This measure is based on the return interval analysis of critical events.
- It gives a critical time for given threshold value and confidence level.
- As an empirical test, we applied the model to data of the Tehran Stock Exchange.

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ABSTRACT

In this paper, we provide a new measure for evaluation of risk in financial markets. This measure is based on the return interval of critical events in financial markets or other investment situations. Our main goal was to devise a model like Value at Risk (VaR). As VaR, for a given financial asset, probability level and time horizon, gives a critical value such that the likelihood of loss on the asset over the time horizon exceeds this value is equal to the given probability level, our concept of Time at Risk (TaR), using a probability distribution function of return intervals, provides a critical time such that the probability that the return interval of a critical event exceeds this time equals the given probability level. As an empirical application, we applied our model to data from the Tehran Stock Exchange Price Index (TEPIX) as a financial asset (market portfolio) and reported the results.

1. Introduction

It is a widely accepted fact that risk matters and it affects manager's and investor's decision making. The first logical consequence that directly follows from this fact is that economic decision makers must manage the risk of economic activities in order to avoid critical events.

The first step of a risk management process is the definition of risk. In finance, risk is the probability that an investment's actual return will be different from what is expected. By this we mean the probability of losing some or all of the original investment [1]. In this definition, risk includes not only "downside risk" but also "upside risk" (returns that exceed expectations). But it must be mentioned that in finance (and also in other fields) when the term risk is used, it implicitly indicates the downside part of the above definition. After the definition and identification of different types of risks, the next step in the risk management process is risk measurement. The risk measurement process mostly comprises risk quantification using different metrics. The importance of risk measurement is such that the innovation and providing of risk metrics, constitutes a significant part of the finance and investment literature.

In a broad classification, with a historical view, one can classify the different risk measures into three classes: volatility measures (including downside and upside risk like variance and semi-variance, etc.), sensitivity measures (e.g. beta,

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duration, semi-beta, etc.) and quantile-based measures (e.g. Value at Risk, etc.). It is the last class, i.e. quantile-based measures which recently attracted many physicists and mathematicians. There are some reasons for this trend. First, these measures are merely based on mathematical or statistical concepts and in contrast with the two other classes are not based on economic assumptions. Second, the advance of information technology made access to large financial data bases easy. This allows physicists and also statisticians to apply a variety of methods to financial data.

Virtually all risk measurement procedures in some way deal with estimation of distribution of financial data. On the other hand, recent progress in information technology allowed the researchers to process large financial data sets. One of the main fruits of this facility is extracting useful information about the distribution of different financial data. Physicists were the first who moved toward the financial markets. This move was a part of a larger movement, so-called Econo-physics. Their main tool is statistical physics. Statistical physics studies systems comprising a very large number of interacting subunits, for which predicting the true behavior of the individual subunit is not possible. Hence, one is restricted to making statistical predictions regarding the collective behavior of the subunits [2]. From the statistical physics point of view, financial markets are complex systems. This is because many investors with different attitudes and predictions and also conflicting interests participate in these markets. On the other hand, randomness of these markets is mostly due to their complexity since a little fluctuation can lead to large crashes. This is why viewing financial markets as complex systems can provide ideal conditions for a better understanding of the stochastic and chaotic behavior of financial markets.

Occurrence of crisis is another common characteristic of all complex systems. If an earthquake is an extreme event in a physical system, a financial crisis (like the recent crisis) can be viewed as an extreme event in financial systems. Based on this, studying the abnormal fluctuations in financial data has been one of the major concerns of economists and physicists in recent years.

The main objective of this paper is to combine extreme event and critical value together with a statistical point of view. Extreme event is a description for a threshold value and critical event is a description for time. In other words, we use a statistical physics method called the Return Interval Approach (RIA) to obtain a critical value (it is better to say critical time) which we use it for calculation of Time at Risk (TaR).

In a seminar held in Moscow in September 2010 entitled 'Time-at-Risk: novel approach to risk management for financial crises and systemic risk', D. Sornette for the first time used the term Time at Risk in the financial literature. Kovalenko and Sornette conceptualized Time at Risk as a working advanced diagnostic system which provides continuous updates on possible scenarios and their probabilistic weights, so that a culture of preparedness and adaptation be promoted. Their concept of Time at Risk reflects the diagnostic of dangerous regimes which is based on the persistence of abnormal market regimes [3].

The concept of Time at Risk (TaR) which we introduce here is different from what Sornette proposed. We proposed a quantile-based approach like the VaR based on the Probability Distribution Function (PDF) of return times of peaks over thresholds. While Value at Risk (VaR) for a given financial asset, probability level and time horizon, provides a critical value such that the probability that the loss on the asset over the given time horizon exceeds this value is the given probability level, our definition of Time at Risk (TaR), using a probability distribution function of return times, provides a critical *time* such that the probability that the return time of a critical event exceeds this time equals the given probability level. Having financial data in hand, one can compare the two approaches mathematically as follows:

$$VaR = f(\alpha) \tag{1}$$

$$TaR = g(\alpha, \rho) \tag{2}$$

where confidence level is $1-\alpha$ and ρ is a level which determines the extreme event. In other words, while *VaR* is a function of only one variable (i.e. level of confidence), *TaR* is a two-variable function and varies as the α or ρ varies. It is needless to say that f and g are thoroughly determined by estimating the distribution function of financial data and the return interval of financial data respectively.

As mentioned above, our main mechanism for obtaining the return interval distribution is the Return Interval Approach (RIA) which is been widely investigated for various financial data [4–9]. The return interval analysis studies the return intervals between events above or below a certain threshold q (see Fig. 1). For example τ_1 measures the time interval between successive normalized return above threshold $q = 1$.

Using RIA for assessing the risk of extreme events is not a new idea. Fernandez and Salas used RIA for measuring risk of extreme hydrological events. They conclude that the evaluation of return periods of critical hydrological events and the corresponding risks of failure of hydraulic structures that are associated with such events are important features in many water resources studies [10]. Recently Bogachev and Bunde used RIA to estimate the Value at Risk (VaR) [11]. Their results suggest that employing the RIA for estimating VaR gives significantly better estimates than conventional methods.

Although the present paper is in line with recent work, it has a clear distinction from past studies. In contrast with previous research, here we do not use RIA for improving the estimation of pre-defined risk measures; rather we use it in order to devise a new risk measure (but still not a new concept). The concept is similar to VaR as the suffix "at Risk" shows: Time at Risk (TaR).

Besides economics, our approach has also many applications in physical systems. Many physical phenomena like climate change and earthquakes are good examples of extreme events. In all these events it is very important to know exactly what is the maximum time at risk or maximum margin of safety at some level of confidence. For instance it is crucial to know how much time at most we have between two successive shocks larger than a threshold at the 99% level of confidence.