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Article

# A Poisson process with random intensity for modeling financial stability

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ABSTRACT

Stock market crashes are hazardous for financial stability and usually modeled via Poisson processes having a predetermined fixed intensity. This study uses a more general framework by allowing the intensity to be random in order to model rare events called the "unpredictable unknowns". Three stock indices, namely Japan Nikkei 225, US Dow Jones Industrial Average and Turkish BIST 100 are analyzed. Simulation results indicate that in stable markets, we encounter fewer unpredictable unknowns compared to unstable ones. However, it is also shown that stable markets are more prone to severe financial crises.

## 1. Introduction

Although there is no precise and universally accepted definition for the term "financial stability", it is usually used in reference to steady growth, reasonable inflation and low unemployment. In the absence of financial stability, high fluctuations will be observed in asset prices. This type of environment leads banks and financial institutions to act in a more prudent manner. There will be credit crunches from banks, shares of risky assets will significantly diminish from portfolios and the volatility of stock prices increase considerably. Hence, movements of stock indices are generally regarded as key indicators of financial stability. A persistent rise in stock prices together with a moderate volatility can be regarded as stable. In case of sudden, unpredictable and sharp breaks, stability deteriorates. Thus, not surprisingly many models have been proposed for detection of breaks throughout the literature (for example Estrella and Mishkin, 1998; Davis and Karima, 2008; Hartmanna et al., 2008; Chen, 2009; Nyberg, 2013).

Peters (1994) proposes the Fractal Market Hypothesis (FMH) by taking the pioneering study of Mandelbrot (1982) as benchmark. His critique is mainly focused on the well-known Efficient Market Hypothesis (EMH) where its basic assumption states that frequency of price changes should well be represented by normal distribution. On the contrary, FMH, which allows heavy tailed distributions says that the market consists of many investors with different investment horizons, and the information set that is important to each investment horizon is different as well. As long as the market maintains this fractal structure, with no characteristic time scale, the market remains stable. When the market's investment horizon becomes uniform, the market becomes unstable. In addition, Mandelbrot and Hudson (2004) introduce the idea of "mild" and "wild" randomness and claim that price changes are neither continuous nor follow a Brownian motion. By the help of fractals they come up with the idea that markets are turbulent and highly risky, have flexible time, contain inevitable bubbles and are deceptive to technical analysis. As stated in Cont and Tankov (2004), Poisson process is a fundamental example of a stochastic process with discontinuous trajectories. They give many examples why Poisson processes are good candidates for modeling financial breaks. In these models, although the exact timing and magnitude of the event is uncertain, the expected number of jumps for an interval is taken to be constant. Moreover, the jump size is either fixed (e.g., Sweeting, 2011) or tied to a specific distribution (for instance Merton, 1976; Kou, 2002). Hence, although random, the average number and the size of the crisis are still known. However, financial markets are less predictable. It is therefore sensible to propose a more general framework for modeling breaks. So, in order to address this unpredictability, the intensity and the jump size should be generalized. Thus, this study aims to consider this need by introducing a Poisson process whose intensity is random.

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Moreover, the jump size is also taken as a function of this new random intensity parameter.

Other than this new mathematical model, this study also aims to introduce a new definition namely the "unpredictable unknowns" (UUs). Unpredictability of an event is a key issue in the sense that its impact is inversely proportional to its predictability. Since this study considers the times where financial stability is severely broken, it is important to distinguish between predictable and unpredictable unknowns.

Bazerman and Watkins (2004) define "predictable surprise" as problems that at least some people are aware of, getting worse over time and likely to explode into a crisis eventually, but are not prioritized by key decision makers or have not elicited a response fast enough to prevent severe damage. For September 11 terrorist attacks they say the following: "When fanatics commandeered jetliners on September 11, 2001, and steered them into buildings full of people, it came as a horrifying shock to most of the world. But however difficult it might have been to imagine individuals carrying out such an act, it shouldn't have been a surprise. Portents had been building up for years. It was well known that Islamic militants were willing to become martyrs for their cause and that their hatred and aggression toward the United States had been mounting throughout the 1990s." They similarly regard the 2008 subprime meltdown as "predictable". Numerous studies are available regarding causality and the predictability of unpredictable events. They are all considered after the occurrence of the event in question. However, if an UU becomes predictable, then it will not be an UU anymore. A critique to Bazerman and Watkins (2004) is the "Black Swan Theory" by Taleb (2007) which is developed to explain surprises beyond the realm of normal expectations in history, science, finance, and technology whose probability is too low thus hard to compute. According to Taleb, an event is deemed to be a black swan if it is a surprise (to the observer), has a major effect and after the first recorded instance, it is rationalized by hindsight, as if it could have been expected; that is, the relevant data available but unaccounted in risk mitigation problems. Contrary to the assertions of Bazerman and Watkins (2004), this study follows the ideas of Taleb (2007) and regard the September 11 attacks or 2008 financial crisis as unpredictable events.

Following the arguments of Taleb (2001, 2007), the following new definition is introduced for a stock market:

**Definition 1.1.** An event is said to be "unpredictable unknown" if it could not be predicted apriorily, caused a historically significant major daily collapse and reversion to the level just before the crisis, that is, the recovery period is too long. Moreover, if the stock market shuts down after the occurrence of this particular event, without taking into consideration of recovery period, it will be deemed as an UU.

The rest of the study is as follows: Section 2 explains some break identification tests. Section 3 provides a literature survey for stochastic processes with jumps. Section 4 analyses three stock indices, namely Japan Nikkei 225, US Dow Jones Industrial Average and Turkish BIST 100. Section 5 describes the theoretical model for the UU events. Section 6 is devoted to simulation results. Finally, Section 7 compares the stock indices mentioned in Section 4 in terms of their financial stability and concludes.

## 2. Identification of breaks

Numerous identification methods are proposed for the determination of breaks in time series.[1] Thus, it would be beneficial to review some of the well-known tests.

Chow (1960) uses a testing procedure to determine whether the coefficients in two linear regressions on different data sets are equal or not. In order to apply Chow test, the suspected break point should priorly be known. Andrews (1993, 2003) extended the Chow test by proposing tests for parameter instability and structural breaks with unknown change points. Bai and Perron (2003) defined a recursive algorithm in which multiple structural breaks can be automatically detected from data. The modulus of continuity notion catches points beyond the possible paths of Brownian motion and regards them as jumps. Hayfavi and Talaslı (2013) use this approach for the identification of breaks where in such a case a constant variance should be stated. Hence one can infer that there is not a single and universally accepted method for jump detection.

## 3. Stochastic processes with jumps

Modeling financial data in continuous time including uncertainty is a major issue. The corresponding driving process is usually assumed to follow a particular pattern. Mean reverting processes drew substantial attention in the literature in which benchmark for these models is the OU process proposed by Ornstein and Uhlenbeck (1930)

$$dS_t = \theta(\mu - S_t)dt + \sigma dB_t \tag{3.1}$$

where $\theta, \mu, \sigma \in \mathbb{R}^+$ and $B_t$ is the standard Brownian motion. Vasicek (1977) is the first mathematician to use (3.1) for modeling interest rates. Here, the process is assumed to revert back to a constant long term mean $\mu$ with a speed of reversion $\theta$. The major drawback of Vasicek Model is argued to be the possibility of negative interest rates (which is quite common nowadays). In order to fix this shortcoming, Dothan (1978), assumes the short term interest rate to be log normally distributed and Cox et al. (1985) take the square root of the interest rates.

Ho and Lee (1986) propose a model where the prices of bonds revert back to the yield curve. Black et al. (1990) and Black and Karasinski (1991) are some alternative models for short term interest rates. In Hull and White (1990), mean is assumed to be an arbitrary function of time. However, mean reverting models cannot explain financial crisis (breaks) since they are continuous. For modeling the jump discontinuities, usually a pure or compound Poisson process is added to (3.1) (for instance Heston, 1993; Bates, 1996; Nielsen and Shephard, 2001). Besides, various mixtures have also been studied. For example, Hayfavi and Talaslı (2013) model the spot electricity prices with an OU process conjoined by a Poisson process for pure jumps and two mean reverting Lévy driven OU processes with different mean reversion rates for spike and semi spikes. Estimating the parameters can sometimes be very problematic. Fitting a model to a certain data becomes difficult when the generality of model increases. Moreover, for models including Lévy processes, other than the parameters, a distribution for explaining the jump structure should also be estimated. Thus, a jump size distribution is usually imposed by statistical methods in an intuitive manner which can be considered as another drawback. In that sense, it can be argued that there is no universally accepted methodology.

## 4. Historical survey of some major stock indices

In this section, the UUs occurred in three stock indices are analyzed.

### 4.1. Nikkei 225 index

From 1914 to 1989 (around 77 years), Nikkei 225 index showed a persistent stability. Even the Black Monday on October 1987 could

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[1] In stochastic analysis breaks are usually referred as jumps.

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