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A spring–block analogy for the dynamics of stock indexes

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HIGHLIGHTS

- Classical models of physics are useful for understanding socio-economic phenomena.
- The spring-model is appropriate for describing avalanche-dynamics.
- The pulled spring–block chain is a useful model for the dynamics of stock indexes.
- The dynamics of a pulled spring–block chain resembles the one of stock indexes.
- The spring–block chain model successfully reproduces the gain–loss asymmetry.

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ABSTRACT

A spring–block chain placed on a running conveyor belt is considered for modeling stylized facts observed in the dynamics of stock indexes. Individual stocks are modeled by the blocks, while the stock–stock correlations are introduced via simple elastic forces acting in the springs. The dragging effect of the moving belt corresponds to the expected economic growth. The spring–block system produces collective behavior and avalanche like phenomena, similar to the ones observed in stock markets. An artificial index is defined for the spring–block chain, and its dynamics is compared with the one measured for the Dow Jones Industrial Average. For certain parameter regions the model reproduces qualitatively well the dynamics of the logarithmic index, the logarithmic returns, the distribution of the logarithmic returns, the avalanche-size distribution and the distribution of the investment horizons. A noticeable success of the model is that it is able to account for the gain–loss asymmetry observed in the inverse statistics. Our approach has mainly a pedagogical value, bridging between a complex socio-economic phenomena and a basic (mechanical) model in physics.

1. Introduction

Spring–block (SB) models have been used for a long time to model complex phenomena in physics and engineering. This model family was introduced by Burridge and Knopoff [1] for describing the distribution of earthquakes after their magnitudes. In its original version a one-dimensional chain of blocks connected by springs is placed on a moving plane. The blocks are free to slide on this plane, subject to a velocity-dependent friction force. All blocks are connected with additional

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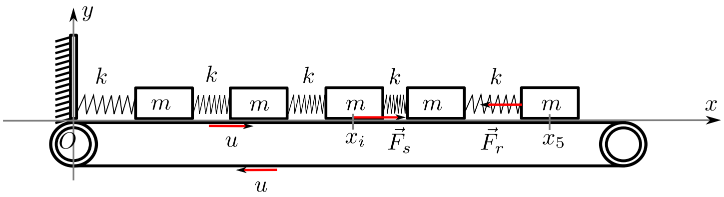

Fig. 1. (Color online) The used spring–block system. Blocks of mass *m* connected by springs with spring constant *k* are placed on a conveyor belt that is moving with a constant velocity *u*.

springs to a second plane, which is in rest, and it is placed above the spring–block chain. This system was meant to describe two tectonic plates that are in relative motion respective to each other, exhibiting a complex stick–slip dynamics. In such an approach the slipping motion of the blocks will lead to energy dissipation and the complex avalanche-like dynamics will yield a scale-free distribution for the energy dissipated in avalanches. The model exhibits a complex dynamics and Self-Organized Criticality (SOC) [2,3].

This very simple physical system formed by an ensemble of blocks interconnected with springs and placed on a frictional surface resulted in many interesting applications. It was successful in reproducing desiccation patterns and dynamics of crack formation in mud, clay or thin layers of paint [4,5], self-organized patterns in wetted nano-sphere [6] or nano-tube [7] arrays or even crack structures obtained in glass [8]. It was applied for describing the Portevin Le Chatelier effect [9] and magnetization phenomena in ferromagnets, including the Barkhausen noise [10]. Besides applications in physics, the spring–block model has some interdisciplinary applications as well. Formation of traffic jams in a single-lane highway traffic [11] or detection of region-like structures [12] in a delimited geographic space are a few recent applications in such sense. Continuing this line of studies, here we intend to consider a simple one-dimension spring–block chain for revealing a pedagogically useful and interesting analogy with the dynamics of stock indexes.

The simplest version of the model will be considered here, the one referred in the literature as "train model" [13]. As it is sketched in Fig. 1, a spring–block chain is placed on a running conveyor-belt, so that the first block is fixed with a spring to an external, static point. As a result of the dragging effect of the conveyor belt, the chain is stretched and a complex-stick–slip dynamics emerges. Both the case of one block alone [14–19] and the case of a chain formed by several blocks [14,16,20–25] were considered in previous theoretical and experimental studies. Coexistence of chaotic dynamics and SOC was observed by many authors [14,25]. Nonlinearity was introduced in the model via friction forces. Several friction force profiles were considered, starting from velocity-weakening friction forces combined with a constant static friction force [14,22,24] to simple state-dependent friction forces [18,25]. Our aim here is rather different from these previous studies. Instead of mapping the dynamical complexity of such a system, we take a different turn and use the system as a simple analogy for modeling the dynamics of stock indexes.

The dynamics of stock indexes are in the focus of physicists from a quite long time [26]. The existence of many *stylized facts* in the financial market (see for example Ref. [26]) captured the interest of the statistical physics community. Simple models have been used to reproduce statistical features of price/index fluctuations (for a review see for example Ref. [27]). Definitely, the most basic approach among them is the simple random walk (or Brownian dynamics) model applied to the logarithmic index [28]. This model is known as the geometric random walk model [29]. The fact that dynamics of stock prices can be approached by a simple geometric random walk is one of the most interesting empirical facts about financial markets. This simple model was first proposed by the French mathematician Louis Bachelier in the early 1900, and it has been strongly debated since then. The most important support for this model comes from the experimental fact that volatility of stock returns tends to be approximately constant in long term. Although this model cannot account of many important statistical aspects of the index or stock price fluctuations (such as time-varying volatility [30,31], evidence of some positive autocorrelations [32], or the asymmetry of the investment horizons distribution for positive and negative return levels [33]), its simplicity and intuitive nature make it pedagogically useful. It can be considered as a first step (zero order model) towards understanding the nature of the stock index dynamics by a general model of mathematics and physics.

Similarly with random walk, the SB system is also a general model of physics, which is appropriate for capturing in an elegant manner universal trends in the dynamics of stock indexes. Although the physical picture behind the two phenomena (motion of a spring–block chain and the dynamics of stock indexes) is rather different, a simple and useful analogy can be drawn between them. This analogy might be useful for pedagogical reasons and for understanding some stylized facts. Our motivation here was not to give a model which performs better than the nowadays used rather complex approaches [34]. Instead of this we focus on the simplicity and visuality of the model, offering a pedagogical picture that is one step ahead of the basic random walk approach. It is important to mention here that very recently it has been already suggested that the price dynamics of the worlds stock exchanges follows a dynamics of build-up and release of stress, similar to earthquakes [35]. In such aspect the endeavor to use an SB system to capture the main characteristics of stock index fluctuations seems even more reasonable.

The rest of the paper is about the proposed analogy between the dynamics of stock indexes and the simple spring–block chain system, and also about discussing the modeling power of such an approach.