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Nonlinearity in high-frequency stock returns: Evidence from the Athens Stock Exchange

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HIGHLIGHTS

- Nonlinearity in Athens Exchange high-frequency returns is studied.
- Intraday volatility periodicity is filtered via a Flexible Fourier Form.
- ARMA–FIGARCH models show that return volatility is long memory and self-similar.
- Nonlinear analysis shows that the filtered data are random.
- The high-frequency data are nonlinear stochastic but not deterministic.

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ABSTRACT

This study investigates empirically the presence of nonlinearities in the Athens Composite Share Price Index high-frequency returns. A preliminary analysis indicates that volatility exhibits a periodic intraday inverse *J*-shaped pattern, associated with the opening and closing of the market. Periodicity is then removed employing a Flexible Fourier Form. Subsequently, an ARMA–FIGARCH model over several frequencies yields that return volatility is long memory and self-similar. Nonlinear analysis with the use of the embedding dimension suggests that the filtered return process does not exhibit deterministic or higher-order stochastic nonlinearity. Rather, it is reminiscent of a random process. We conclude that the ACSPI data are nonlinear; however, nonlinearity is attributed to persistent ARCH effects.

1. Introduction

In equity markets, the assessment and reduction of risk are of profound importance in decision making, for both short and long term investments. Thus, intense research efforts have been devoted to the modeling and forecasting movements of financial returns, resulting in a large corpus of literature. In this respect, of particular interest has been the detection of nonlinearities in financial returns, the existence of which allows for improved risk assessment and speculative opportunities [1,2]. However, such studies remain cumbersome to conduct due to (a) the presence of noise in the data and (b) the limited number of observations. The employment of high-frequency data can partially circumvent (b); still, the presence of nonlinearities (or not) in such time series is an open issue.

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The aim of this study is to empirically investigate whether the Athens Exchange Composite Share Price Index (hereafter, ACSPI) high-frequency returns exhibit nonlinear dependences. This aim is served first by exploring for long memory in return volatility, and second by testing for deterministic or higher-order stochastic nonlinearity in the return process.

The presence of long memory in volatility of financial market returns has been well-documented in literature [3–10]. In this regard, a common suggestion has been that long memory is attributed to a large number of volatility components that involve various degrees of persistence. For instance, Müller et al. [11] proposed that such volatility components are implied by the presence of heterogeneous market agents who differ in their expectations and investment strategies. Similarly, Andersen and Bollerslev [12] suggested that a long memory volatility process expresses the aggregation of numerous heterogeneous information arrival processes, that imply various levels of intraday (short-run) and interday (long-run) volatility persistence. Moreover, should a long memory variance process be the outcome of heterogeneous components, then dependence in each component will exhibit a slow hyperbolic decaying rate that is invariant of the sampling frequency [12,13].

The uncovering of volatility persistence in high-frequency returns has been a rather challenging task, due to the presence of intraday periodicity. For instance, there has been widespread evidence that the intraday volatility pattern of, round-the-clock traded, exchange rates is mainly driven by daily global financial activity cycles; e.g., opening and closing of major exchanges [14,15]. By contrast, organized futures and spot markets operate under limited time-schedules. Therefore, intraday volatility in such markets exhibits regular or asymmetric U-shaped patterns, that are related to the elevated market stress at the start and the end of the daily trading session [3,16–18]. Such periodic patterns may induce biases to estimates of short-run persistence in volatility, thus, investigation for long memory is typically conducted on periodicity-adjusted intraday returns [19].

An effective method for approximating and removing intraday periodicity in market return volatility is the Flexible Fourier Form technique, originally developed by Gallant [20]. Andersen and Bollerslev [3] employed this filter to remove volatility periodicity in the high-frequency Deutsche-Mark/US Dollar exchange rate returns and the US S&P 500 index futures returns. Furthermore, and via GARCH models, the authors provided consistent evidence of volatility persistence in the de-seasonalized time series. In a similar manner, the long memory property of volatility has been established in a wide range of currency, futures and spot markets [4,5,13,15,19,21–26].

In contrast to the well-evidenced long memory property of volatility, empirical studies on other types of nonlinearity in financial returns have been rather inconclusive. On one hand, there has been a broad consensus on the presence of deterministic nonlinear dependence, that is possibly related to chaotic behavior [1,2,27–30]. On the other hand, several empirical studies have found little evidence of nonlinear determinism in the return process [4,21,31–33].

The present study contributes to the existing literature on nonlinear behavior of financial returns in two main ways. Firstly, even though similar studies on Athens Exchange interday based data have been conducted in the past [31,34,35], to the best of our knowledge this is the first study of nonlinearity in Athens Exchange (hereafter, ATHEX) high-frequency returns. Furthermore, most empirical studies of nonlinearity in intraday stock returns have focused on major exchanges; mainly for US, UK and Japan [13,15,33,36–39]. Such markets typically involve considerable amounts of trading activity and, therefore, high levels of information speed. By contrast, in less active markets investors usually react slowly to the arrival of new information. Hence, biases due to the non-synchronous construction of prices and other microstructure effects are expected to be more severe, as compared to the developed capital markets [31]. To this extent, it has been deemed useful to examine the case of an emerging market, like ATHEX.

Secondly, to investigate the existence of hidden deterministic or of higher-order stochastic nonlinearity in the ACSPI high-frequency data, we employ non-linear analysis techniques based on the notion of the embedding dimension, such as the BDS test [40] and the estimation of correlation dimension [41], Kolmogorov–Sinai entropy [42] and Lyapunov exponents [43]. Although most empirical studies on high-frequency stock returns have focused on the long memory property of volatility (e.g., Ref. [15] for the Japanese market and Refs. [23,26] for the Korean market), such types of nonlinearity have not yet received sufficient empirical attention. Notable exceptions are the early studies by Hsieh [33], Abhyankar et al. [36,37], Mayfield and Mizrach [38], and the most recent study by BenSaïda [39], that found little evidence of nonlinear determinism in the major equity spot markets. Rather, these studies collectively suggested that nonlinearity in the high-frequency returns is mostly attributed to stochastic dependences.

Herein, the ACSPI returns are initially de-seasonalized with the Flexible Fourier Form technique, following Andersen and Bollerslev [3]. Then, an ARMA(υ, l)–FIGARCH(p, δ, q) model is employed for the de-seasonalized returns. Thus, inference on the presence of persistent ARCH effects is based on the estimated long memory parameter, δ, in the FIGARCH specification [4,21,26], whereas the nonlinear analysis with the use of the embedding dimension is conducted on the filtered returns. The use of prewhitened returns in the nonlinear analysis reduces the possibility of biased inference due to the presence of autocorrelation in the mean and variance process of the raw returns. In Mayfield and Mizrach [38] and Abhyankar et al. [36,37], a GARCH filter was employed for volatility clustering. However, in the above studies the data were not de-seasonalized. Also, in BenSaïda [39], the tests for noisy chaos were conducted on raw high-frequency returns.

The rest of the paper is organized as follows. Section 2 describes the ACSPI data-set. Section 3 provides preliminary analysis for the ACSPI returns. Section 4 sets out the methodology. Section 5 presents and discusses the empirical results. Finally, Section 6 concludes the paper.