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How fast do stock prices adjust to market efficiency? Evidence from a detrended fluctuation analysis

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ABSTRACT

In this paper we analyse price fluctuations with the aim of measuring how long the market takes to adjust prices to weak-form efficiency, i.e., how long it takes for prices to adjust to a fractional Brownian motion with a Hurst exponent of 0.5. The Hurst exponent is estimated for different time horizons using detrended fluctuation analysis – a method suitable for non-stationary series with trends – in order to identify at which time scale the Hurst exponent is consistent with the efficient market hypothesis. Using high-frequency share price, exchange rate and stock data, we show how price dynamics exhibited important deviations from efficiency for time periods of up to 15 min; thereafter, price dynamics was consistent with a geometric Brownian motion. The intraday behaviour of the series also indicated that price dynamics at trade opening and close was hardly consistent with efficiency, which would enable investors to exploit price deviations from fundamental values. This result is consistent with intraday volume, volatility and transaction time duration patterns.

1. Introduction

The market efficiency hypothesis [1,2] states that asset prices adjust to fully reflect all available information and so show martingale behaviour. Although the formulation of this hypothesis refers to a rapid and unbiased price adjustment process, in practice, prices tend not to adjust to new information instantly but after a certain amount of time. During this time investors take actions to exploit temporary profit opportunities arising from new information, ultimately pushing prices towards efficiency. The time the market takes to adjust prices to market efficiency is an important dimension of the market efficiency hypothesis [3], with notable practical implications for trading and risk management.

The adjustment of asset prices to information has been widely studied at the theoretical and empirical level. Theoretical models have been developed by Grossman [4], Grossman and Stiglitz [5] and Cornell and Roll [6], in which the incorporation of stock price information depends on the cost of information production. For a rational expectation framework, Brown and Jennings [7] and Grundy and McNichols [8] show how prices adjust in a sequence of trades to fully reveal all relevant information. For a model populated by Bayesian traders, Chakrabarti and Roll [9] found, in a simulation study, that the market usually converged more rapidly to an equilibrium price when arbitrageurs reacted to one another. Behavioural finance models have been developed by Barberis et al. [10], Daniel et al. [11] and Hong and Lee [12] to provide explanations for empirically documented under- and over-reactions of stock prices to news.

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Empirically, several studies have examined market efficiency in terms of the speed with which prices react to new information arising from any specific event e.g., [13] or in a more general setting with no specific event identified e.g., [14]. Early tests of weak-form market efficiency employed the linear autocorrelation test and the Lo and Mackinlay variance ratio test [15] for daily, weekly and monthly stock returns. However, those tests assume linearity e.g., [16,17,12], so they only check for serial uncorrelatedness rather than for the martingale property of asset returns.

There is no reason to suppose that stock prices are intrinsically linear. Human error in reasoning or information processing (e.g., information bias or overconfidence) may explain information imperfections in financial markets [18] that may give rise to price nonlinearity. Nonlinearity may also arise from price fads, rational speculative bubbles [17] or the assumption that prices are the result of complex interactions between informed and uninformed traders in the market place. Nonlinearity in stock returns is crucial for forecasting see, e.g., [19,20] and for determining the speed of convergence to market efficiency since zero autocorrelation does not imply the martingale property of asset returns. Statistical tests developed by Hurst [21], Brock et al. [22] and Peng et al. [23] are considered superior to the linear autocorrelation tests as they are able to detect the presence of short- and long-term dependence. Based on those tests, we propose a different approach to the problem of measuring the adjustment time of security prices towards weak-form market efficiency. This approach is based on employing detrended fluctuation analysis (DFA) [23] for different intraday time scales in order to identify the time horizon necessary for prices to adjust to a fractional Brownian motion (fBm) with a Hurst exponent of 0.5. The chief advantages of the DFA methodology compared with traditional methods (e.g., Hurst analysis, rescaled range statistic, root mean square, time-varying long-range dependence) are that (a) it allows self-similarity to be detected in nonstationary time series and so allows, in turn, log price to be analysed, and (b) it avoids the spurious detection of apparent long-range correlation by excluding the intrinsic trend of the financial time series.

DFA has been used for dynamic analysis, among others, of heart rate variability [24], human electroencephalographic fluctuations [25] and economic and financial series [26–32]. In particular, DFA has been recently employed to study market efficiency [33–37], even though all the existing empirical studies using DFA have analysed the efficiency at specific time scales without analysing the time the market takes to achieve weak-form efficiency. This is the focus of our study.

The remainder of the article is organized as follows. Section 2 provides a brief theoretical review and describes the DFA methodology for estimating the Hurst parameter to quantify the speed of adjustment of prices to a random walk; Section 3 describes our data; Section 4 reports our empirical results; and, finally, Section 5 concludes the article.

2. Methodology

The time dependence structure of a stochastic process can be captured by the autocorrelation function. Long memory, characterized by autocorrelations at very high lags, creates persistence (anti-persistence) in the series over long time horizons. In such cases, autocorrelation declines at a hyperbolic rate that is slower than the exponential rate in standard autoregressive moving average (ARMA) processes. Mills [38] suggested that many empirically observed time series, even though they may appear to satisfy the assumption of stationarity with or without differentiation, seem to exhibit dependence between distant observations that, even if small, is by no means negligible. The many approaches to estimating the long memory parameter (fractional differencing) include, in financial time series, the autoregressive fractionally integrated moving average model, ARFIMA (p, d, q), which has the desired ability to match the slow decay of the autocorrelation functions. The difference between the ARFIMA (p, d, q) model and the autoregressive integrated moving average model, ARIMA (p, d, q), is that the former does not restrict the parameter d to being an integer value but allows it to take a fractional value. For noninteger values of d, the autocorrelation declines hyperbolically. When $0 < d < 0.5$ the ARFIMA process is said to exhibit long memory with positive dependence. For $d = 1$ the ARFIMA process is therefore identical to an ARIMA in that the autocorrelations decay exponentially. For $d = 0$, the ARFIMA process is reduced to an ARMA process and exhibits only short memory and for $-0.5 < d < 0$ the ARFIMA process exhibits long memory with negative dependence.

2.1. Hurst exponent

To quantify financial fluctuations it is necessary to calculate and graph the autocorrelation function for price changes in a log–log plot. Obtained is a power law equation where the slope is the scaling exponent H, invariant under appropriate changes. Different techniques based on fractal analysis suggest that market data exhibit temporal correlations and fat-tailed probability distributions. Temporal correlation means that volatile fluctuations tend to occur with a particular trend, while fat-tailed probability distribution means that a more extreme event might be more frequent than a normally distributed event. The fractal concept, which is linked to time scale invariance, is used to identify the order in characteristic nonlinear problems.

DFA is a method developed by Peng et al. [23], Moreira et al. [39], Peng et al. [40] and used to determine the quantitative Hurst exponent H, which represents the correlation properties of a signal. Based on analysing fluctuations in a time series for different time scales, DFA focuses on removing the trend of a signal, which should not be related to the correlation properties of the signal. A trend may be produced by joint price movements in other markets. Under these circumstances it is very important to be aware if the trend can be filtered, as an intrinsic trend may be related to the local signal fluctuation properties. In general, DFA-q is the variable used to eliminate the first-order trend $q = 1$; in other words, the function