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Using conditional probability to identify trends in intra-day high-frequency equity pricing

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ABSTRACT

By examining the conditional probabilities of price movements in a popular US stock over different high-frequency intra-day timespans, varying levels of trend predictability are identified. This study demonstrates the existence of predictable short-term trends in the market; understanding the probability of price movement can be useful to high-frequency traders. Price movement was examined in trade-by-trade (tick) data along with temporal timespans between 1 s to 30 min for 52 one-week periods for one highly-traded stock. We hypothesize that much of the initial predictability of trade-by-trade (tick) data is due to traditional market dynamics, or the bouncing of the price between the stock's bid and ask. Only after timespans of between 5 to 10 s does this cease to explain the predictability; after this timespan, two consecutive movements in the same direction occur with higher probability than that of movements in the opposite direction. This pattern holds up to a one-minute interval, after which the strength of the pattern weakens.

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1. Introduction

In this paper we examine the predictability of market directional movements using high-frequency data in a popularly-traded stock by examining the prior movements. If the upward and downward price movements are systematic, rather than random in nature, this knowledge should help traders better predict the direction of the stock and make more informed trading decisions.

Mainstream finance theory has traditionally held the view that financial prices are efficient and follow a random walk. The definition of a random walk is a process where the changes from one time period to the next are independent of one another, and are identically distributed. One of the earliest studies of market efficiency was done by Fama in 1965 to describe how equity prices at any point in time best represent the actual intrinsic value, with the prices updating instantaneously to information [1]. Efficiency is associated with a trendless and unpredictable financial market.

According to the theory of random walks and market efficiency, the future direction of a stock is no more predictable than the path of a series of cumulative random numbers [1]. Statistically it can be said that each successive price is independent of the past; each series of price changes has no memory. If testing for market independence, the probability of market directional-movement at time t is compared against time $t - 1$. The same should hold as more prior information is added since, according to market efficiency, the past cannot be used to predict the future.

The theory of random walks and efficiency of market prices was expanded by Fama in Ref. [1] to the Efficient Market Hypothesis (EMH) in the 1960's. The theory states that the current market's price is the correct one, and any past information is already reflected in the price. According to the EMH, although no market participant is *all knowing*, collectively they know as much as can be known; for as a group, they *are* the market. These individuals are constantly updating their beliefs about

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the direction of the market, and although they will disagree on the direction of the stock, this will lead, as noted by Fama, to "a discrepancy between the actual price and the intrinsic price, with the competing market participants causing the stock to wander randomly around its intrinsic value [1]". If markets are indeed efficient, then it implies that markets never overreact or underreact during the trading day. Any effort that an average investor dedicates to analyzing and trading securities is wasted, since one cannot hope to consistently beat the market. Any attempt to predict future prices is futile and although high rates of return may be achieved, they are on average, proportional to risk. In addition, high risk may achieve high rates of return, but it also can deliver high rates of loss. For example, when flipping a fair coin, a roughly 50% chance of getting heads would be expected; however, expecting heads ten times consecutively would come with high risk. The concept of an efficient market implies that consistently predicting the market carries a high risk.

For those who believe that markets are predictable, there are two main schools of thought: the "technician" and the "fundamentalist". Fundamental analysts look at the external and economic factors to determine price change. The belief is that since stocks are shares of a corporation, examining the fundamental indicators such as profits, sales, debt levels, and dividends should provide an outlook into the future direction of the price. Technical analysts believe that the past performance of equities can help forecast future price movements. They study historical prices to try and understand the psychology of other market participants (the crowds). The technician attempts to identify regularities in the time-series of price or volume information; the thought is that price patterns move in trends, and that these patterns often repeat themselves [2,3]. There is a skew toward technical analysis over fundamental analysis when considering shorter (intra-day) time horizons. This paper examines the technical approach.

Trading filters, as first used by Alexander [2], attempted to show predictability, and therefore the existence of trends, by using quantitative rules based on prior price history to create profits by buying and selling. If markets are random, zero profits would be expected over a baseline amount; however, if a model can be introduced that shows apparent profitability, then this opens the possibility of markets that occasionally trend. According to Granger and Timmermann [4], the existence of a single successful trading model would be sufficient to demonstrate a violation of the market efficiency hypothesis. A number of empirical studies using daily data, such as Neely et al. [5], Osler and Chang [6], Levich and Thomas [7], and Sweeney [8] found profitability of trading rules in excess of the risks taken. The consensus of these papers is that the market is predictable, by way of trading rule profitability, at least part of the time.

Timmermann [9] however, found forecasting models that use daily and longer interval data to predict stock returns mostly performed poorly. He did find some evidence of short-lived instances of predictability, thus requiring the examination of intra-day trading data. The theory is that if there are more instances of a particular high-probability pattern during a timespan, they will more likely be spotted by other traders and implemented in their trading strategy. This widespread adoption of a particular trading approach drives the asset price either up or down enough to eliminate the pattern. Furthermore, while it is common for professional traders to use intra-day data, this short time horizon is often under-represented in the academic literature.

Ohira et al. [10], Tanaka-Yamawaki [11], Sazuka [12], and Hashimoto et al. [13] examined market data at the lowest intra-day level available, trade-by-trade (sometimes known as tick data) and found extremely high levels of predictability. For example, in Refs. [10,11] the authors report predictability as high as 79.7% and 75.0% respectively. While the movements are clearly predictable and raise doubt as to the efficiency of the currency market, we theorize here that much of the predictability in those two papers can be explained by the noisy continuation[1] of the bid–ask market dynamics.[2] While the *bid–ask bounce* has been discussed in academic literature previously, we believe this is the first study of this size (dataset includes 15 billion in share volume) and level of detail (number of intervals examined) that examines when a stock escapes the confines of the bid and ask spread. To escape the noisy influence of bid–ask market dynamics, some researchers have sampled the market at even intervals such as 5, 10, and 60 min intervals. A paper by Reboredo et al. [16] found profitability over a benchmark for 5, 10, 30, and 60 min intervals of intra-day data using Markov switching, artificial neural networks and support vector machine regression models. Additionally Wang and Yang [17] found intra-day market inefficiency in the energy markets using 30 min intra-day prices.

Our research demonstrates however, in most cases, the market has gone back to efficiency after a one-minute timespan. We empirically examine the conditional probabilities of upward versus downward movements by using intra-day timespans of trade-by-trade (tick) data along with nine temporal timespans of 1, 3, 5, 10, 20, and 30 s and 1, 5, and 30 min for 52 separate one-week periods in 2005 of a popularly traded stock, the Standard and Poor's 500 index (symbol: SPY). By investigating the conditional probabilities, we find that the market escapes the confines of the bid–ask spread after a 5–10 s timespan. An additional contribution of this paper is the observation of trends with seemingly high predictability; trends that have high occurrences of continuing rather than going against the trend, unless the trend is broken.

In Section 2, we explore efficiency and conditional probability within high-frequency stock data and why market dynamics may explain some of the market predictability. Within this section we also explain how sampling methods have been used to eliminate the noise associated with the bid–ask spread. In Section 3, we describe our dataset and demonstrate our

[1] "Continuation" is a term used by Ref. [14] and refers to the pattern where the signs of at least two non-zero consecutive changes are in the same direction. See also Section 3.3.

[2] While the currency-spot market is different from the equity market, such as the absence of a reported last trade/transaction, market dynamics still apply [15]. The large number of participants and lack of a centralized reporting facility cause the bid and ask to fluctuate in the currency-spot market, similar to the last trade/transaction in the equity market bouncing between the bid and ask.

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