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(How) has the market become more efficient?

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ABSTRACT

Using a portfolio of Dow Jones Industrial Average index constituents and the index ETF, we document significant intraday deviations from the law of one price. These are especially pronounced at very short time intervals. The extent of deviations is related to volatility, liquidity, and transaction costs of both the index constituents and the ETF. Further, the influence of news arrival, and liquidity (volatility) shocks on the deviations persists for several hours. Finally, we document significant decline (by at least 80%) in the deviations between 1998 and 2010. We find that this decline is largely due to decimalization, the repeal of the uptick rule, and the introduction of automated updating of the NYSE order book. Overall, our findings indicate an increase in operational market efficiency.

1. Introduction

The law of one price (LOP) is among the most fundamental concepts in finance and the assumption of its validity lies at the very core of most theoretical finance literature. The implicit assumption in the literature has been that security prices provide an unbiased estimate of their intrinsic value at all times and therefore, the law of one price must hold at all times. In reality, the elimination of the violations from the LOP involves costs.[1] Such costs include, among others, transaction costs, information acquisition and processing costs, as well as those induced by excessive volatility. The presence of these costs suggests that apparent violations of the law of one price may persists, especially at the intraday level.[2] Yet, the extent to which the LOP holds at an intraday level and, more importantly, factors that influence deviations from it, have only recently started attracting attention of researchers.[3] In this paper, we fill this gap in the literature by answering the following questions. How well does the LOP hold at the intraday frequency? What factors influence deviations from the LOP? Have the recent changes in financial markets and regulations (e.g., decimalization, the repeal of the uptick rule) influenced the extent of deviations from the law of one price?

We answer these questions by examining the intraday deviations from the law of one price for the Dow Jones Industrial Average (DJIA) index and the SPDR Dow Jones Industrial Average ETF (DIA). Fundamentally, these two assets (the ETF and the portfolio of 30 DJIA stocks) are identical and therefore any information flow should affect them both in an identical manner. Hence, (the traditional view of) the law of one price would argue that the two asset returns should be indistinguishable from each other at all times. We show that this is not the case – there are statistically significant deviations from the law of one price for all time intervals we examine (from one-minute to 60-min). First, we find the largest deviations for the one-minute time interval and the smallest for the 60-min one. A decrease of time interval from 60-min to one-minute increases tracking error by a factor of 24. Second, we find that the above deviations from the LOP are positively related to volatility and negatively related to liquidity, transaction costs, and the pace of trading. We also find that the negative relationship

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[1] Jensen (1978) defines market efficiency as the inability to make positive "risk-adjusted returns net of all costs" (p. 96).

[2] For the law of one price to hold at any point of time investors should be able to implement an arbitrage strategy fast and at reasonable transaction costs. Also, according to Grossman and Stiglitz (1976), the markets need to provide enough arbitrage profits to compensate the arbitragers for their costs of information acquisition. Further, as suggested by French and Roll (1986), excess volatility and therefore mispricing induced by noise trading may persist for a period of time.

[3] See, e.g., Akram et al. (2009), Marshall et al. (2013), and Levy and Lieberman (2013).

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between deviations from the law of one price and trading volume is driven primarily by the activities of algorithmic traders.

Third, our intraday tracking errors allow us to examine the magnitude and persistence of the influence of the new information arrival (macroeconomic announcements) as well as liquidity and volatility shocks on market efficiency. We find that the influence of these events on tracking errors persists for a considerable length of time. In particular, the influence of new information (volatility shock) on tracking errors declines rather rapidly in the first 30 (50) minutes, but is still present for another 3 (6) hours (h). The liquidity shock, on the other hand, has a significant and more persistent influence for 3 h. Further, we examine the influence of tracking errors on the index and ETF order flows. We find that tracking errors influence index order flow for about two-and-a-half hours, while their influence on ETF order flow lasts for about 2 min.

Fourth, we document that during our sample period (1998–2010) deviations from the LOP have decreased by at least a factor of five. The deviations for the intermediate time intervals (five-, ten-, and 15-min ones) have declined by as much as 88%. Fourth, we identify three events that have had the most significant influence on the deviations from the law of one price: decimalization, the repeal of the uptick rule, and the introduction of automated updating of the New York Stock Exchange (NYSE) order book. All of these events have significantly increased investors' ability to implement an arbitrage strategy. First, decimalization significantly increased the liquidity of US stock market (see, e.g., Gibson et al., 2003). Second, by making its entire order book available to investors continuously, the NYSE has significantly increased investors' access to information in a timely manner (see, e.g., Boehmer et al., 2005). Third, the repeal of the uptick rule also increased the investors' ability to implement arbitrage strategy by allowing them to short-sell at any time.

Our paper is related and contributes to several streams in the finance literature. First, the law of one price has been examined in a variety of contexts (see, e.g., Lamont and Thaler, 2003; Choi et al., 2010). Of the literature on the stock indexes and ETFs, the main focus has been on the arbitrage opportunities with the futures and options markets. For example, Park and Switzer (1995), Chu and Hsieh (2002), and Switzer et al. (2000) show increased pricing efficiency in the futures markets after introduction of index ETFs. Richie et al. (2008) show that mispricing between ETF and index futures continues to exist even after the introduction of the S&P500 ETF (SPDR). We contribute to this literature by examining the intraday deviations from the law of one price for the DIA and the portfolio of 30 DJIA index stocks.

Second, we contribute to the literature examining factors influencing the extent of deviation from the law of one price (see, e.g., Roll et al., 2007). Engle and Sarkar (2006) suggest that the existence of (daily) premiums and discounts in the ETF pricing (vis-à-vis the underlying basket) may be attributed to market frictions, limits to arbitrage, stale prices, and difference in treatment of dividends. Using daily data, Petajisto (2011) shows that, even after correcting for stale prices and differences in dividend timings, a trading strategy designed to arbitrage the tracking error between the ETF and the underlying basket generated an alpha of 11% per year from 2007 till 2011. He suggests that this pricing inefficiency can be at least partly attributed to the differences in the liquidity of the underlying asset since larger mispricing is observed for ETFs with relatively illiquid underlying assets.[4] In addition to highlighting the importance of volatility, liquidity, and transaction costs, we contribute to this literature by documenting the importance of algorithmic traders in decreasing the extent of deviations from the law of one price. In addition, we document the importance of better access to complete information in a timely manner (due to the introduction of automated quote updating of the NYSE order book) and the relaxation of the short sale restrictions (due to the repeal of the uptick rule). Finally, we use intraday tracking errors to examine the magnitude and persistence of the influence of new information as well as liquidity and volatility shocks on market efficiency.

Third, we contribute to the literature on ETF tracking errors. Using daily data, Ackert and Tian (2000) find economically insignificant discount of SDPR relative to the underlying S&P500 index. They conclude that arbitrage forces are strong enough to eliminate the impact of noise traders, noting that the redemption feature of SPDR potentially plays a role in keeping prices efficient. Low tracking error between ETF and underlying index (at daily time interval) is also supported by several other studies such as Tse and Martinez (2007) and Rompotis (2010). We provide evidence on the levels as well as the changes in tracking errors at intraday frequency.

Our paper has implications for any study involving a time-series comparison of either stock returns or volatility. In particular, our findings of a significantly lower extent of deviations from the law of one price implies that prices now more fully reflect the entire spectrum of investors' beliefs than they did in 1990s. Consequently, the market reaction upon a news event might be different now as compared to 1990s purely because of the changes documented in this paper.[5] Similarly, a better reflection of investors' beliefs also implies lower mispricing and consequently, smaller stock price corrections (see, e.g., Ofek and Richardson, 2003), and therefore lower volatility.

The remainder of the paper is organized as follows. Section 2 develops our testable hypotheses. Section 3 describes the data, while Section 4 presents the testing methodology and reports results. Section 5 concludes with a brief discussion of the implications of our findings.

2. Hypotheses development

The implicit assumption in much of the finance literature has been that the law of one price has to hold at any point of time. There are, however, several reasons why this assumption may not hold. First, according to Grossman and Stiglitz (1976, 1980), costs of information is one of the reason why the market cannot be efficient at all times. They argue that the market needs to provide enough arbitrage profits to compensate the arbitragers for their costs of information acquisition. In fact, Grossman and Stiglitz (1980) go as far as saying that "because information is costly, prices cannot perfectly reflect the information which is available, since if it did, those who spent resources to obtain it would receive no compensation" (p. 405). In our setting, implementation of the arbitrage involves ensuring timely access to prices of all index constituents (as well as the price of the ETF) and using the correct weights for each stock when establishing a position. These are costly in terms of both time and money, suggesting that violations of the law of one price are likely to be present, especially at short time intervals.

Second, as highlighted by French and Roll (1986), the presence of noise trading may induce mispricing, which may persist for a period of time. A similar prediction is made by De Long et al. (1990), who argue that the unpredictability of noise traders' beliefs creates a risk in the price of the asset that deters rational arbitrageurs from aggressively betting against them. As a result, prices can diverge significantly from fundamental values even in the absence of fundamental risk.

[4] See also literature on the determinants of the closed-end fund discount (e.g., Pontiff, 1996; Lee et al., 1991; Gemmill and Thomas, 2002).

[5] This will be true if historically one type of information (either good or bad) has not been reflected in stock prices. See Miller (1977) who argues that, in the presence of short sale constraints, the negative information will not be reflected in the prices.