Sources of stock return autocorrelation

Robert M. Anderson [a,*], Kyong Shik Eom [b], Sang Buhm Hahn [c], Jong-Ho Park [d]

[a] University of California at Berkeley, Department of Economics, 530 Evans Hall #3880, Berkeley, CA, 94720-3880, USA

[b] University of Seoul, Siripdae-gil 13, Dongdaemun-gu, Seoul, 130-743, Korea

[c] KCMI, 45-2 Yoido-dong, Youngdeungpo-gu, Seoul, 150-974, Korea

[d] Sunchon National University, 315 Maegok-dong, Sunchon, Chonnam, 540-742, Korea

ABSTRACT

We decompose stock return autocorrelation into spurious components—the nonsynchronous trading effect (NT) and bid-ask bounce (BAB)—and genuine components—partial price adjustment (PPA) and time-varying risk premia (TVRP), using three key ideas: theoretically signing and/or bounding the components; computing returns over disjoint subperiods separated by a trade to eliminate NT and greatly reduce BAB; and dividing the data period into disjoint subperiods to obtain independence for statistical power. We also compute the portion of the autocorrelation that can be unambiguously attributed to PPA. Analyzing daily individual and portfolio return autocorrelations in sixteen years of NYSE intraday transaction data, we find compelling evidence that PPA is a major source of the autocorrelation.

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* Corresponding author. Tel.: +1-510-642-5248. Fax: +1-510-642-6615.
E-mail address: anderson@econ.berkeley.edu (R.M. Anderson).
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1. Introduction

One of the most visible stylized facts in empirical finance is the autocorrelation of stock returns at fixed intervals (daily, weekly, monthly). This autocorrelation has presented a challenge to the main models in continuous-time finance, which rely on some form of the random walk hypothesis. Consequently, there is an extensive literature on stock return autocorrelation; it occupies four segments totaling 55 pages of Campbell, Lo, and MacKinlay (1997). The results of this literature were, however, inconclusive; see the Literature review in Section 2.

This paper presents a comprehensive analysis of daily stock return autocorrelation on the New York Stock Exchange (NYSE). Our goal is to show that simple methods, applied to intraday data, allow us to resolve the questions concerning *daily return autocorrelation* left unanswered by the literature. Daily return autocorrelation has been attributed to four main sources: spurious autocorrelation arising from market microstructure biases, including the nonsynchronous trading effect (NT) (in which autocorrelations are calculated using stale prices) and bid-ask bounce (BAB), and genuine autocorrelation arising from partial price adjustment (PPA) (i.e., trade takes place at prices that do not fully reflect the information possessed by traders) and time-varying risk premia (TVRP).[1] The term "spurious" indicates that NT and BAB arise from microstructure sources which bias the autocorrelation tests.[2] This bias

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[1] The momentum effect has been cited as an explanation of medium-term (3 to 12 months) autocorrelation (see Jegadeesh and Titman (1993)). The momentum effect is properly viewed as a form of PPA. We make no attempt in this paper to model PPA, and thus need not be concerned with the various forms of trader behavior that can give rise to it. Rather, we present methods to decompose return autocorrelation into the various components. In addition, the medium-term momentum effect is of little relevance to daily return autocorrelation, which is the focus of the empirical work reported here.

[2] Our use of the terms "spurious" to describe the NT and BAB effects and "genuine" to describe PPA and TVRP follows the terminology of Campbell et al. (1997). On pages 84-85, Campbell et al. (1997) write "For example, suppose that the returns to stocks A and B are temporally independent but A trades less frequently than B. … Of course, A will respond to this information eventually, but the fact that it responds with a lag induces spurious cross-autocorrelation between the daily returns of A and B when calculated with *closing* prices. This lagged response will also induce spurious own-autocorrelation in the daily returns of A" [emphasis in original]. On page 100, they write "Moreover, as random buys and sells arrive at the market, prices can bounce back and forth between the ask and bid prices, creating spurious volatility and serial correlation in returns, even if the economic value of the security is unchanged." We do not view the term "spurious" as pejorative in any sense.

would produce the appearance of autocorrelation even if the underlying "true" securities price process were a process such as geometric Brownian motion with constant drift.

In this paper, we make use of three key ideas: signing and/or bounding the contributions of NT, BAB, and TVRP to stock return autocorrelation; eliminating NT by computing returns over disjoint return subperiods, separated by a trade; and measuring autocorrelation over disjoint time-horizon subperiods to obtain independence for statistical power. Using these three methods, we are able to isolate a portion of the daily return autocorrelation which could only come from PPA, and is thus genuine, rather than spurious.

Open-to-close return is defined as closing price today, minus opening price today, divided by opening price today. By contrast, conventional daily return is defined as closing price today, minus closing price yesterday, divided by closing price yesterday. We argue that autocorrelations computed from open-to-close returns are free of NT and essentially free of BAB. Anderson (2011) shows that TVRP is sufficiently small that it can be ignored in the setting considered here: daily return autocorrelation tests on a two-year time-horizon subperiod.[3]

We examine sixteen years worth of Trade and Quote (TAQ) data from 1993 through 2008, broken into eight two-year time-horizon subperiods. In each subperiod, we select 1,000 stocks representing the full spectrum of market capitalization on the NYSE; these 1,000 stocks are classified into 10 groups of 100 stocks by market capitalization. We apply our three key ideas to both individual stock return autocorrelation and portfolio return autocorrelation.

The following are our main findings for *individual* stock return autocorrelation:

- We reject the hypothesis that the average individual conventional stock return autocorrelation is zero, and the hypothesis that the conventional return autocorrelation for each stock is zero. The autocorrelations are predominantly positive in the first half of our data period (1993-2000), and predominantly negative in the second half (2001-2008). The positive autocorrelations can only come from PPA, while the negative autocorrelations may come

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[3] If the expected return on a security varies over the time-horizon subperiod, it results in positive autocorrelation that standard autocorrelation tests cannot distinguish from PPA. The bias resulting from TVRP in the *p*-values in hypothesis tests depends in a complex way on the return period, the time horizon over which the autocorrelations are calculated, and the variability of the risk premium over the time horizon. This bias may be big enough to matter in empirical settings other than the one considered here. See Anderson (2011) for details.

from any combination of NT, BAB, or PPA.

- We also reject the hypothesis that the average individual open-to-close stock return autocorrelation is zero, and the hypothesis that the open-to-close return autocorrelation for each stock is zero. Even though this approach excludes NT and BAB, the results are qualitatively similar to those obtained with conventional returns. The autocorrelations are predominantly positive in the first half of our data period, and predominantly negative in the second half. Both the positive and negative autocorrelations can only arise from PPA.

We study portfolio return autocorrelation first by taking each of our size groups as an equally-weighted portfolio, using both conventional and open-to-close returns on the individual stocks in the portfolio. Second, we consider the conventional daily return autocorrelation of SPDRs, an Exchange-Traded Fund (ETF) based on the Standard and Poor's 500 (S&P 500) Index. Finally, we analyze the correlation between past returns on the SPDRs and future returns on the individual stocks in each of the size groups by counting the number of stocks with statistically significant autocorrelation in each size group and each two-year return subperiod. The following are our main findings for *portfolio* return autocorrelation:

- We reject the hypothesis that the conventional portfolio return autocorrelation is zero. In the first half of our data period, the autocorrelations are positive. In the second half of our data period, only two portfolios show significant autocorrelation, and both are negative. The positive autocorrelations can reflect any combination of NT or PPA, while the negative return autocorrelations can only reflect PPA.
- We also reject the hypothesis that the open-to-close portfolio return autocorrelation is zero. Even though this approach excludes NT, the results are qualitatively similar to those obtained with conventional returns. In the first half of our data period, the autocorrelations are positive and significant in nine of the ten size portfolios, but in the second half, only four of ten portfolios show significant autocorrelation, and all four are negative. Both the positive and negative autocorrelations can only arise from PPA.
- We find that PPA is the main source of portfolio return autocorrelation in all time subperiods and all size groups except the largest; even there, it falls just below 50%.
- We find that the conventional return autocorrelation of the SPDRs is negative and statistically significant; this could only come from PPA or BAB. We bound BAB in terms of the relative

spread ratio of the SPDRs, and correct the autocorrelation to eliminate any possible negative autocorrelation arising from BAB. We find that PPA is the main source of the negative autocorrelation in the SPDR returns.

- We find that past returns of the SPDRs predict future returns of individual stocks. The autocorrelations are predominantly positive in the first half of our data period; in the second half, the significant autocorrelations are found mostly in the five smallest size cohorts and are mostly negative. These autocorrelations can only come from PPA.

In summary, daily return autocorrelation remains a very prominent feature of both individual stocks and portfolios on the NYSE, in all firm size groups and across eight two-year subperiods of our sixteen-year data period. While microstructure biases (NT and BAB) and TVRP contribute to return autocorrelation, PPA is an important source and in some cases the predominant source of this autocorrelation. PPA results in positive autocorrelation (slow price adjustment) in some long periods of time and negative autocorrelation (overshooting) in other long periods. In particular, there is a significant paradigm shift between 1993-2000 and 2001-2008, and this shift affects both individual stock and portfolio return autocorrelation across all firm size groups in a consistent direction, from more positive autocorrelation towards more negative autocorrelation. This consistent shift most likely reflects either an increase in the popularity of momentum strategies, resulting in overshooting, or an increase in the volume of high-frequency trading, or a combination of the two.

The remainder of this paper is organized as follows. Section 2 reviews the literature on daily return autocorrelation. Section 3 details our methodology and null hypotheses. Section 4 describes the sampling of firms and provides descriptive statistics of our data. Section 5 presents and interprets the empirical results. Section 6 provides a summary of our results and some suggestions for further research.

2. Literature review

In this section, we review the literature on daily stock return autocorrelation. There has been considerable controversy over the *proportion* of the autocorrelation that should be attributed to each of the four components: NT, BAB, PPA, and TVRP.

Since Fisher (1966) and Scholes and Williams (1977) first pointed out NT, the extent to which it can explain autocorrelation has been extensively studied, but remains controversial. Butler, Atchison, and

Simonds (1987) and Lo and MacKinlay (1990) find that NT explains only a small part of the portfolio autocorrelation (16% for daily autocorrelation in Butler et al. (1987); 0.07, a small part of the total autocorrelation, for weekly autocorrelation in Lo and MacKinlay (1990)). Bernhardt and Davies (2008) find that the impact of NT on portfolio return autocorrelation is negligible. However, Boudoukh, Richardson, and Whitelaw (1994) find that the weekly autocorrelation attributed to NT in a portfolio of small stocks is up to 0.20 (56% of the total autocorrelation) when the standard assumptions by Lo and MacKinlay (1990) are loosened by considering heterogeneous nontrading probabilities and heterogeneous betas;[4] they conclude that "institutional factors are the most likely source of the autocorrelation patterns."

The use of intraday data has led to renewed interest in this issue. For example, Ahn, Boudoukh, Richardson, and Whitelaw (2002), citing Kadlec and Patterson (1999), conclude that "nontrading is important *but not the whole story* [italics added]." Ahn et al. (2002) assert that the positive autocorrelation of portfolio returns "can most easily be associated with market microstructure-based explanations, as partial [price] adjustment models do not seem to capture these characteristics of the data."

Most studies of autocorrelation in individual stock returns have focused on the average autocorrelation of groups of firms, finding it to be statistically insignificant and usually positive; see Säfvenblad (2000) for a cross-country survey. For example, Chan (1993) models the effect of NT, and predicts that individual stock returns show no autocorrelation, while portfolio returns exhibit positive autocorrelation due to positive cross-autocorrelation across stocks. Testing this model, Chan (1993) finds support for positive cross-autocorrelation, and for his prediction that the cross-autocorrelation is higher following large price movements.

Chordia and Swaminathan (2000) compare portfolios of large, actively traded stocks, to portfolios of smaller, thinly traded stocks, arguing that NT should be more significant in the latter than in the former. The data they report on the autocorrelations of these portfolios "suggest that nontrading issues cannot be the sole explanation for the autocorrelations […] and other evidence [concerning the rate at which prices of stocks adjust to information] to be presented."

Llorente, Michaely, Saar, and Wang (2002) and Boulatov, Hendershott, and Livdan (2011) model the effect of PPA on autocorrelation. Both papers consider the effect of informed traders using their information

[4] Boudoukh et al. (1994) report first-order autocorrelation of 0.23 for weekly returns of an equally-weighted index and 0.36 for weekly returns of a small-stock portfolio.

slowly (as in Kyle (1985)). Llorente et al. (2002) argue that positive autocorrelation arises if speculative trading predominates over hedging.[5] In the model of Boulatov et al. (2011), the fundamental values of different securities are correlated. They find that the sensitivity of informed traders' strategies in a particular asset is positive in the signal for that asset and negative in the signal for the other assets, so that a past increase (decrease) in the price of one asset predicts a future increase (decrease) in the price of other assets.

To the best of our knowledge, no paper has asserted that time-varying risk premia are a significant source of autocorrelation in the empirical setting considered here, daily returns of individual stocks and portfolios over two-year periods.[6] Nonetheless, time-varying risk premia do induce some bias in standard autocorrelation tests; Anderson (2011) estimates an upper bound on that bias and finds that it is not significant in the empirical setting of this paper.

Over the last two decades, as increasing computer power and new statistical methods have permitted the analysis of very large datasets using intraday data, the focus has shifted from autocorrelation at fixed intervals to the varying speed of price discovery across various assets. The price discovery literature clearly establishes PPA.[7] However, because that literature has paid little attention to daily return

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[5] Using a variety of methodologies, Chordia and Swaminathan (2000), Llorente et al. (2002), and Connolly and Stivers (2003) find support for the partial price adjustment hypothesis. See also Brennan, Jegadeesh, and Swaminathan (1993), Mech (1993), Badrinath, Kale, and Noe (1995), McQueen, Pinegar, and Thorley (1996), Baur, Dimpfl, and Jung (2012).

[6] Conrad and Kaul (1988, 1989) and Conrad, Kaul, and Nimalendran (1991) (hereafter collectively abbreviated as CKN) estimate that predictable time-varying rates of return can explain 25% of the variance in weekly and monthly portfolio returns. They do not apply their methodology to daily returns; if they had, they presumably would have found a somewhat smaller percentage. As noted in Anderson (2011), predictable time-varying rates of return are simply autocorrelation by another name, and are not necessarily attributable to TVRP. CKN invoke a strong form of the Efficient Markets Hypothesis to assert that, since anyone could in principle exploit any knowledge of the TVRP, there cannot be any exploitable information. Since testing for PPA is, in effect, testing a version of the Efficient Markets Hypothesis, we are unwilling to impose the Efficient Markets Hypothesis as an assumption. The predictable expected rates of return estimated by CKN vary substantially from week to week, and we find it implausible that TVRP vary this much over the span of a week or two; see Ahn et al. (2002, page 656), who note that "time variation in [risk premia] is not a high-frequency phenomenon: asset pricing models link expected returns with changing investment opportunities, which, by nature, are low-frequency events" (the original says "expected returns," but it is clear from the context that by this, they meant risk premia as we use the terms in this paper).

[7] For example, Ederington and Lee (1995), Busse and Green (2002), and Adams, McQueen, and Wood (2004)

autocorrelation, it does not tell us whether or not PPA plays a significant role in daily return autocorrelation. Since daily return autocorrelation remains one of the most visible stylized facts in empirical finance, it is desirable to have a clear understanding of its sources and their respective magnitudes.

3. Methodology

3.1. Key ideas

As noted by Lo and MacKinlay (1990), NT arises from measurement error in calculating stock returns. If an individual stock does not trade on a given day, its daily return is reported as zero.[8] Think of the "true" price of the stock being driven by a positive (negative) drift component, the equilibrium mean return, plus a daily mean-zero volatility term, with the reported price being updated only on those days on which trade occurs. On days on which no trade occurs, the reported return is zero, which is below (above) trend; on days on which trade occurs after one or more days without trade, the reported return represents several days' worth of trend; this results in spurious negative autocorrelation.

Even if a stock does trade on a given day, the reported "daily closing price" is the price at which the

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established that the incorporation of publicly-released information into securities' prices is not instantaneous. However, we are not aware of any previous evidence that the slow incorporation of publicly-released information is a factor in daily return autocorrelation. When private information is possessed by some agents and *not* released publicly, Kyle (1985) predicts that informed agents will strategically choose to exercise their informational advantage slowly, over several days, and this slow price adjustment has the potential to generate daily return autocorrelation. Because the private information of traders is generally not observable, one cannot usually apply the methods of Ederington and Lee (1995); Busse and Green (2002); and Adams et al. (2004) to the incorporation of private information into prices. Kim, Lin, and Slovin (1997) were able to study the incorporation of private information, in a situation in which favored clients were given access to an analyst's initial buy recommendation prior to the opening of the market. They found "For NYSE/AMEX stocks, almost all of the private information contained in analysts' recommendations is reflected in the opening trade;" if so, this would not result in autocorrelation of conventional daily returns or of open-to-close returns, as we compute them here.

[8] Because our primary focus is separating PPA from NT, we need to use intraday transaction data, and thus we use the NYSE TAQ dataset. The Center for Research in Security Prices (CRSP) dataset reports the average of the final bid and ask quotes as the "closing price" so that returns calculated from CRSP data will generally not be zero on no-trade days.

last transaction occurred, which might be several hours before the market closed. Thus, a single piece of information that affects the underlying value of stocks *i* and *j* may be incorporated into the reported price of *i* today because *i* trades after the information is revealed, but not incorporated into the reported price of *j* until tomorrow because *j* has no further trades today, resulting in a positive cross-autocorrelation between the prices of *i* and *j*.

Hence, NT causes spurious negative individual autocorrelation and positive individual cross-autocorrelation, resulting in positive autocorrelation of portfolios.

3.1.1. Key idea 1: sign and/or bound the sources of autocorrelation theoretically

The first key idea in this paper is to theoretically sign and/or bound the various sources of autocorrelation, so that we may draw inferences about the source from the sign of the observed autocorrelation.

- NT is negative for individual stock returns, and is generally positive for portfolio returns.
- BAB is negative for both individual stock and portfolio returns, and is generally considered to be very small for portfolio returns.[9] Some of our tests greatly reduce BAB. Thus, we shall assume that for all but one of our portfolio tests, the contribution of BAB to portfolio return autocorrelation is zero.[10]
- PPA can be either positive or negative for both individual stock and portfolio returns.[11]

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[9] In a portfolio of stocks, the individual stocks are traded; the portfolio itself is not traded, and its price is obtained by averaging the prices of the individual stocks it contains. Thus, while the price of an individual stock may bounce between the bid and ask, there is no bid or ask between which the portfolio price jumps. If the bounce process, which determines whether a given trade occurs at the bid or ask price, were independent across different stocks, bid-ask bounce would produce a slight negative autocorrelation in portfolio returns coming from the negative autocorrelation of the individual stocks in the portfolio; the cross bid-ask bounce effects would be zero. In practice, the bounce process probably shows positive correlation across stocks; if stock prices generally rise (fall) just before the close, then most stocks final trade will be at the ask (bid) price, inducing negative autocorrelation in the daily portfolio return. Thus, bid-ask bounce should cancel some of the positive autocorrelation in daily portfolio returns that results from NT, PPA, and TVRP.

[10] In one test (autocorrelation of SPDRs), we are able to bound BAB and find it is too small to explain the negative autocorrelation.

[11] Inventory costs should lead specialists to make transitory adjustments in prices in order to bring their inventories

- TVRP is positive for both individual stock and portfolio returns. For plausible values of the variation in risk premia, TVRP is too small to affect the tests in this paper (Anderson (2011)).

Consequently, in the discussion of our tests, we shall assume there are only three sources, (NT, BAB, and PPA) for daily return autocorrelation of individual stocks, and only two sources (NT and PPA) for daily portfolio return autocorrelation. If we find statistically significant positive autocorrelation in individual stock returns, it can only come from PPA. If we find statistically significant negative autocorrelation in portfolio returns, it can only come from PPA. The signs are summarized in Table 1.

<Insert Table 1>

3.1.2. Key idea 2: eliminate NT by computing returns over disjoint return subperiods, separated by a trade

The second key idea in this paper is to study stock returns over *disjoint* time intervals where a *trade occurs between the intervals*. More formally, we study the correlation of stock returns over intervals [s,t] and [u,v] with $s < t \leq u < v$ such that the stock trades at least once on the interval [t,u]. We apply this idea to derive tests in a number of different situations. Because these correlation calculations do not make use of stale prices, NT is, *by definition*, eliminated; if the correlation turns out to be nonzero, there must be a source, other than NT, for the correlation. This conclusion does not depend on any particular story of how the use of stale prices results in spurious correlation.

We say that a stock exhibits PPA if there are trades at which the trade price does not fully reflect the information available at the time of the trade. Let r_{sti} denote the return on stock i (i=1,…,I) over the time interval [s,t]; in other words, $r_{sti}=\frac{S_i(t)}{S_i(s)}-1$, where $S_i(t)$ is the price of stock i at the last trade occurring at or before time t. Since $S_i(t)$ is observable, and hence part of the information available at time t, the

back to the desired level (see Lyons (2001), pages 130-133). Because the mean reversion of specialists' inventories has quite a long half-life (Madhavan and Smidt (1993)), it seems unlikely that inventory costs are a significant source of *daily* return autocorrelation. Although the autocorrelation resulting from inventory costs is often described as a microstructure *bias*, we see it as a form of PPA. The specialist deliberately adjusts the stock price above (below) the price that equates traders' buy and sell orders in order to increase (reduce) his inventory to the desired level, then gradually lowers (raises) the price, even though the inventory imbalance conveyed no information. The autocorrelation results from the slow decay of the adjustment.

absence of PPA in stock j implies the following:[12]

> given times $s < t \leq u < v$ such that stock j trades at some time $w \in [t,u]$, r_{uvj} is uncorrelated with r_{stj}.

Thus, we can test for the presence or absence of PPA by examining return correlations over time intervals $[s,t]$ and $[u,v]$ satisfying the condition just given.

Two of our tests focus on what we call open-to-close returns; in these tests, NT is eliminated, and BAB is greatly reduced. The open-to-close return of a stock on a given day is defined as the price of the last trade of the day, less the price at the first trade of the day, divided by the price at the first trade of the day. Thus the open-to-close return of stock i on day d is $r_{s_i t_i i}$, where s_i and t_i are the times of the first and last trades of the stock on day d.[13] We compute the correlation $\rho(r_{s_i t_i i}, r_{u_i v_i i})$, where u_i and v_i are the times of the first and last trades on day d+1. Note that $s_i < t_i < u_i < v_i$, so NT is eliminated.

BAB arises in conventional daily return autocorrelation because the correlation considered is $\rho(r_{q_i t_i i}, r_{t_i v_i i})$, where q_i is the time of the last trade prior to day d. Note that the end time in calculating $r_{q_i t_i i}$ is the same as the starting time in calculating $r_{t_i v_i i}$, resulting in negative autocorrelation, as explained in Roll (1984); Roll's model assumes that at each trade, the toss of a fair coin determines whether the trade occurs at the bid or ask price. In the calculation of the open-to-close autocorrelation, the end time t_i of the first interval is different from the starting time u_i of the second interval. Moreover, the trades at t_i and u_i are different trades, so the coin tosses for these trades are independent; if we apply Roll's model to this situation, the autocorrelation resulting from BAB is zero. If we extend Roll's model to multiple stocks, and assume the coin tosses are independent across stocks, the autocorrelation and cross-autocorrelation of open-to-close stock returns are zero. Relaxing the independence assumption results in slightly negative autocorrelation and cross-autocorrelation of open-to-close returns.[14]

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[12] More precisely, the absence of PPA and TVRP imply the stated conclusion.

[13] Since there is no trade in the stock after time t_i, the open-to-close return also equals $r_{s_i t i}$, where t is the closing time.

[14] The assumption in Roll's model that the coin tosses are independent across trades is restrictive. Choi, Salandro, and Shastri (1988) showed that serial correlation of either sign in the coin tosses affects the magnitude, but not the sign, of the autocorrelation in conventional daily returns induced by BAB. Positive (negative) serial correlation in the coin tosses of a given stock induces negative (positive) autocorrelation of open-to-close returns, but it appears that the magnitude is much smaller than that of the autocorrelation of conventional daily returns. It seems likely that the serial correlation of the coin tosses is positive, so we expect BAB to induce slight negative autocorrelation

In this paper, we assume that BAB does not contribute to autocorrelation in open-to-close returns of individual stocks or portfolios.[15] This seems completely innocuous in the context of portfolio returns, since the consensus is that BAB plays no significant role in the autocorrelation of conventional portfolio returns, and its role in open-to-close portfolios would be even smaller. For individual stock open-to-close returns, note that the relevant coin tosses are those for the last trade one day and the first trade the next day. A lot happens overnight: a considerable amount of information comes in from news stories, corporate and governmental information releases, and foreign markets. Limit orders can be set to expire at the close of trade one day, allowing the trader to place new limit orders the next day, taking any new information into account. It seems to us that the overnight information flow amounts to a thorough randomization that should pretty much eliminate correlation in the value of the two coin tosses used in our analysis.[16] However, a reader who is still concerned by the assumption that open-to-close individual stock return BAB is zero should note that BAB will result in negative bias in our autocorrelation estimates. It could

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of individual stock open-to-close returns. If we extend Roll's model to multiples stocks, and assume that the coin tosses are independent *across stocks*, the cross-autocorrelations induced by BAB will be zero. It is unclear how restrictive the assumption of independence of the coin tosses across stocks is. If the coin tosses are correlated across stocks, it appears that the correlation should be positive: if the market as a whole is rising, this seems likely to cause buyers to raise their bids to match the current ask; if the market as a whole is falling, this seems likely to cause sellers to lower their asks to match the current bid. Positive correlation of the coin tosses across stocks would result in negative cross-autocorrelation in daily returns, and slight negative cross-autocorrelation in open-to-close returns.

[15] An alternative method for reducing BAB would be to use the midpoint of the closing buy and sell quotes as the closing price. As has been noted in the literature, computing returns from the midpoint of the bid and ask quotes reduces BAB, but need not completely eliminate it; see for example, Hasbrouck (2007, page 91). The most important issue for us is separating NT from PPA. PPA is characterized by *trades* occurring at prices that do not fully reflect the information available. If we were to compute returns using the midpoint of the bid and ask quotes, rather than actual trades, then our tests would not establish the role of PPA in daily return autocorrelation. Using the midpoint of the bid and ask quotes is probably better for the specific purpose of controlling for BAB, but is not helpful for our main goal, separating NT from PPA. We chose to use a method which clearly separates NT from PPA, and which is helpful for reducing BAB.

[16] Note that if the indicator draws are independent, the realized string of indicators will exhibit mean reversion: each indicator, a bid or an ask, is at the extreme, and the expected value of the second indicator, which is a bid half the time and an ask half the time, equals the mean. While there may be positive serial correlation in the indicator in successive trades on a single day, we are not aware of any paper that finds positive serial correlation between the indicator on the last trade one day and the first trade the next day.

thus possibly bias our negative autocorrelation findings, but it makes it harder to find statistical significance in our positive autocorrelation findings. This issue is discussed in the results section, for the particular null hypotheses where it arises.

3.1.3. Key idea 3: measure autocorrelation over disjoint time-horizon subperiods to obtain independence for statistical power

The third key idea is to divide the data period into disjoint time-horizon subperiods, and note that under the assumption that the theoretical autocorrelation is zero, the sample return autocorrelations within disjoint time-horizon subperiods are independent, so we may derive tests using the binomial distribution.

This idea is applied in two settings. In the first setting, we compute a single sample autocorrelation in each subperiod; in one case, we compute the average of individual stock return sample autocorrelations over each subperiod, while in another case, we compute the sample portfolio return autocorrelation over each subperiod. We count the number of time-horizon subperiods in which the single autocorrelation value is statistically significant at the two-sided (+/-) 5% level, and use the binomial distribution to compute *p*-values. We do tests over the eight two-year time-horizon subperiods within 1993-2008; we also break our data period into two halves (1993-2000 and 2001-2008) and break each half into four two-year time-horizon subperiods.

The binomial distribution yields the *p*-values indicated in Table 2:

<Insert Table 2>

In the second setting, we apply the binomial distribution to counts of stocks with statistically significant return autocorrelations in each of the time-horizon subperiods. We consider separately positive only (+), negative only (-), and positive or negative (+/-) rejections using a one-sided 2.5% rejection criterion for + and for -, and a symmetric 5% rejection criterion for +/-. If the correlation tests were independent across firms, the number of rejections would have the binomial distribution. If the collection $\{ r_{s_i t_i i} : i = 1, \ldots, I \}$ were a family of independent random variables, then X, the number of firms for which the zero-correlation hypothesis is rejected at the 5% (2.5%) level, would be binomially distributed, as $B(I, 0.05)$ ($B(I, 0.025)$), which has mean $0.05I$ ($0.025I$) and standard deviation $\sqrt{(.05)(.95)I}$ ($\sqrt{(.025)(.975)I}$). Since returns are not independent across stocks, X will not be binomial. The standard deviation of X is not readily ascertainable, and is likely higher than that of the binomial. However, the failure of independence does not change the mean of X, so X is a nonnegative, integer-valued, random variable with mean $0.05I$ ($0.025I$).

In all of these tests, there are I=100 firms, so X has mean μ=5 or μ=2.5. Since X is nonnegative, $P(X \geq \alpha\mu) \leq 1/\alpha$ for every $\alpha \geq 1$. Suppose that we compute X in each of n disjoint time-horizon subperiods. This provides us with n independent observations of X; let $X_1, \ldots, X_n$ be the order statistics, i.e., X_1 is the smallest observation, X_2 the second smallest, and so forth. Then using the binomial distribution, for every $\alpha \geq 1$, $P(X_1 \geq \alpha\mu) \leq 1/\alpha^n$ and $P(X_2 \geq \alpha\mu) \leq 1/\alpha^n + n(1-1/\alpha)/\alpha^{n-1} = (n\alpha - (n-1))/\alpha^n$. Given particular realizations $x_1 \geq \mu$ and $x_2 \geq \mu$ of X_1 and X_2, we obtain p-values of $p_1 = 1/(x_1/\mu)^n$ for x_1 and $p_2 = (n(x_2/\mu) - (n-1))/(x_2/\mu)^n$ for x_2, respectively. The test for the k^{th} order statistic X_k involves the combinatorial coefficient $n!/((k-1)!(n-k+1)!)$ as well as the factor $(\mu/x_k)^{n-k+1}$, both of which grow rapidly with k. Thus, the power of the test for X_k declines rapidly with k, suggesting the test be based on X_1 alone. However, the test for X_1 can be strongly affected by a single outlier. In particular, if any single realization of X is less than μ, then p_1=1 and the null hypothesis will not be rejected. For these reasons, we adopt a combined test using the minimum of the p-values p_1 and p_2, rather than using the higher order statistics. Note that for any γ, $P(min\{p_1,p_2\} \leq \gamma/2) = P(2\ min\{p_1,p_2\} \leq \gamma) = P(p_1 \leq \gamma/2 \text{ or } p_2 \leq \gamma/2) \leq P(p_1 \leq \gamma/2) + P(p_2 \leq \gamma/2) = \gamma/2 + \gamma/2 = \gamma$. Thus, we compute $p_3 = 2\ min\{p_1,p_2\}$, the correct p-value for the combined test. Note that p_3 depends on μ and n.[17]

As a robustness check, we also compute the average of the p-values across the time periods. Specifically, let $Y_1, \ldots, Y_n$ denote the n independent observations of X, in time order rather than order statistics. Since $P(\mu/Y_i \leq 1/\alpha) \leq 1/\alpha$ for all $\alpha \geq 1$, the unknown true distribution of μ/Y_i, is first-order stochastically dominated by the uniform distribution on [0,1]. We compute the statistic $p_4 = (\mu/Y_1 + \ldots + \mu/Y_n)/n$, and determine significance levels for this statistic using Monte Carlo simulation using the uniform distribution on [0,1]. The significance results are qualitatively similar to those obtained using p_3 derived from the order statistics, as just described.

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[17] There is a trade-off between the number of time-horizon subperiods and the lengths of the time-horizon subperiods. Because stock returns are very noisy, for a given return period, it is much easier to detect autocorrelation in longer time-horizon subperiods than in shorter time-horizon subperiods. On the other hand, the statistical power of the order statistic tests increases when the number of independent observations (the number of time-horizon subperiods) increases. In preliminary work, we experimented with both one-year and two-year time-horizon subperiods, and found qualitatively similar results.

3.2. Individual stock returns

Previous studies of individual stock return autocorrelation have focused on the average autocorrelation of groups of firms, finding it to be statistically insignificant and usually positive (Säfvenblad (2000)). This finding does not rule out the possibility that some stocks exhibit positive autocorrelation and others exhibit negative autocorrelation, with the two largely canceling out when averaged over stocks. None of the previous studies analyzed the autocorrelation of individual stocks one by one. This is the focus of our analysis, because it allows us to test whether the autocorrelation arises from PPA; as a comparison to the previous literature, we also compute the average autocorrelation over groups of firms, segregated by firm size. We calculate the autocorrelation in two different ways: the conventional daily return autocorrelation, and the open-to-close return autocorrelation.

3.2.1. Conventional daily return autocorrelation

For each firm, we calculate the daily return on each day in the conventional way: the closing price on day *d*, minus the closing price on the last day prior to day *d* on which trade occurs, divided by the closing price on the last day prior to day *d* on which trade occurs. When we compute individual stock returns in the conventional way, NT and BAB are both present, and both generate negative autocorrelation. **Null Hypothesis I** is that the *average* daily return autocorrelation is zero in each firm-size group in each of our eight two-year time-horizon subperiods; we test this hypothesis by comparing the average sample daily return autocorrelation for each subperiod to the associated standard error. In each firm-size group and two-year time-horizon subperiod, we do a two-sided test with a 5% rejection criterion. Positive rejections can only come from PPA; negative rejections can arise from a combination of NT, BAB, and PPA.

On the assumption that the theoretical return autocorrelations are zero, the average sample autocorrelations are independent across disjoint time-horizon subperiods, the number of subperiods on which a hypothesis is rejected has the binomial distribution, with the *p*-values noted above as a function of the number of subperiods in which rejection occurs.

We also compute the average autocorrelation in each firm-size group in the whole sixteen-year period. There are 800 sample autocorrelations (100 stocks times eight subperiods) in each firm-size group; we average these 800 observations and report the standard error.

Null Hypothesis II is that *every* firm's conventional daily return exhibits zero autocorrelation. For each firm, we test whether daily returns exhibit zero autocorrelation, in each of n=8 disjoint two-year time-horizon subperiods, using + and - one-sided test with a 2.5% rejection criterion, as well as a +/- two sided test with a 5% rejection criterion. Positive rejections can only come from PPA; negative rejections could come from any combination of NT, BAB, and PPA. In each subperiod, the + and – tests correspond to μ=2.5, while the +/- two-sided test corresponds to μ=5.[18] Applying this test to 100 firms in each of the eight disjoint subperiods, we reject Null Hypothesis II if $p_3 < 0.05$. In the alternate test using p_4, the average of the p-values, we reject based on the values determined by our Monte Carlo simulation.

3.2.2. Open-to-close return autocorrelation

As above, we define the open-to-close return on day *d* as the price at the final trade on day *d*, minus the price at the first trade on day *d*, divided by the price at the first trade on day *d*. If a given stock does not trade, or has only one trade, on a given day, we drop the observation of that stock for that day from our dataset.[19]

If we compare open-to-close returns on day *d* and day *d*+1, there is *no* NT effect: the open-to-close returns are computed over disjoint time intervals, with each interval beginning and ending with a trade, so stale prices never enter the calculation. Moreover, because the first trade on day *d*+1 is a different trade from the last trade on day *d*, BAB is sufficiently reduced so that it can be ignored; see the extended comments on this point in Section 3.1.2. If PPA makes no contribution to stock return autocorrelation, the theoretical autocorrelation of open-to-close returns on each stock must be zero.

As with the conventional daily return, we use one-sided + and – tests, and a two-sided +/- test. **Null Hypothesis III** is that the *average* autocorrelation of open-to-close returns is zero in each of the eight two-year time-horizon subperiods in each group of stocks. The testing procedure and rejection criteria

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[18] The specific tests for autocorrelation will be described in Section 3.4.

[19] The reader might have expected us to set the open-to-close return of that stock to be zero for that day. Doing so could introduce an NT bias for essentially the same reason that imputing a zero return on days on which a given stock does not trade induces negative autocorrelation in individual daily stock returns. The results when the observations are included and set to zero are essentially the same.

are identical to those for Null Hypothesis I. Rejection of Null Hypothesis III, whether positive or negative, implies that PPA contributes to stock return autocorrelation. As in the case of conventional returns, we also compute the average autocorrelations over the entire sixteen-year period.

Our **Null Hypothesis IV** is that the autocorrelation of open-to-close returns on *each* stock is zero in each two-year subperiod. The testing procedure and rejection criteria are identical to those for Null Hypothesis II. Rejection of Null Hypothesis IV, whether positive or negative, implies that PPA is a source of individual stock return autocorrelation.

3.2.3. Analysis of autocovariance

The three key ideas outlined above allow us to identify certain elements of autocorrelation that can only come from PPA. In this section, we describe a method to obtain a lower bound on the portion of the individual stock autocovariance attributable to PPA. Conventional daily returns are calculated from the closing trade one day to the closing trade of the next day on which trade occurs; the union of these intervals, from one closing trade to the next, covers our data period 24 hours per day, 7 days per week. However, the open-to-close returns of the stocks are calculated over a portion of the data period, namely the union of the intervals of time beginning with the first trade of a stock on a day and the last trade of the same stock on that day. A portion of the period when the markets are open, and the entire period when the markets are closed, are omitted.

In all conventional models of stock pricing, the standard deviation of open-to-close return should be lower than the standard deviation of conventional daily return. For example, if the stock price is any Itô Process, the realizations of the volatility term over the excluded intervals are uncorrelated with the realizations over the included intervals. Since the variance of a sum of uncorrelated random variables is the sum of the variances, the exclusion of the intervals must decrease the variance.

Notice that this argument applies to the theoretical variance—the variance of the theoretical distribution of returns. The observed variance of returns for a given stock is the variance of a sample out of that theoretical distribution of returns, so the standard deviation of open-to-close return might be larger than the standard deviation of conventional daily return for a few stocks. In our sample, we find that only 113 of the 8,000 stock-subperiod pairs (1,000 stocks per time-horizon subperiod times eight subperiods) exhibit sample standard deviation of open-to-close returns greater than the sample standard deviation of conventional daily return, and only two of 8,000 are significant at the 5% level. Similarly, we find in all 80 of our portfolio-subperiod pairs that the variance of open-to-close portfolio returns is lower than the variance of conventional daily portfolio returns.

For each stock, we can compute the conventional daily (open-to-close) return autocovariance by taking the product of the conventional daily (open-to-close) return autocorrelation times the conventional daily (open-to-close) return variance. Note that these autocovariances can be either positive or negative, so it is not appropriate to compute their ratio. However, we know that PPA is the only source of the open-to-close return autocovariance. If C_i and I_i denote the conventional daily and open-to-close return autocovariances of stock *i*; $C_i - I_i$ denotes the residual. C_i, I_i, and $C_i - I_i$ may each be either positive or negative. Thus, we consider $\frac{|I_i|}{|I_i| + |C_i - I_i|}$ as the fraction of the identifiable absolute autocovariance arising from open-to-close returns. This ratio is a lower bound on the portion of the identifiable return autocorrelation attributable to PPA. It understates the proportion of the autocorrelation attributable to PPA for two reasons. First, PPA can induce both negative and positive effects; these cancel, and we see only the net effect in this calculation. Second, PPA occurring between the last trade of a stock on a given day and the first trade on the next day is also omitted from this calculation.

3.3. Portfolio returns

While many papers have studied whether NT can fully explain positive portfolio autocorrelation, all of the tests have been indirect. In this paper, we propose and carry out two direct tests that eliminate NT. In both tests, we compute the correlation of returns of securities over disjoint time intervals separated by a trade, so that stale prices never enter the correlation calculation. If NT and BAB are the sole explanations of portfolio return autocorrelation, the autocorrelation computed by our methods must be less than or equal to zero.

As a preliminary test, we consider conventional portfolio returns as a benchmark. The conventional daily return of a portfolio is defined to be an equally weighted average of the conventional daily returns of the individual stocks in the portfolio. **Null Hypothesis V** is that the conventional daily return autocorrelation is zero in each of the ten portfolios and each of the eight two-year time-horizon subperiods.

3.3.1. First method, open-to-close returns

In the first method, we compute the open-to-close returns of each individual stock as defined in Section 3.2.2.[20] As noted there, open-to-close returns on different days do not exhibit NT, and BAB should be essentially eliminated. In each two-year time-horizon subperiod, we consider each of the ten groups of 100 stocks, grouped by market capitalization, that were used in our individual stock return studies: we form a portfolio from each group.

We define the open-to-close return of a portfolio on a given day as the equally-weighted average of the open-to-close returns for that day on all stocks in the portfolio, omitting those stocks which have fewer than two trades on that day. Note that the autocorrelation of the open-to-close return of the portfolio is just the average of the correlations of the open-to-close returns of the individual pairs (including the diagonal pairs) of stocks in the portfolio. Since 99% of these pairs are off-diagonal, the portfolio return autocorrelation is dominated by the cross-autocorrelations between pairs of stocks. In particular, the portfolio return autocorrelation is *not* the average of the individual return own autocorrelations of the stocks in the portfolio.

If PPA makes no contribution to portfolio return autocorrelation, the theoretical autocorrelation of the open-to-close return of the portfolio must be zero. Thus, our **Null Hypothesis VI** is that the autocorrelation of the open-to-close return of the portfolio is zero in each of the eight two-year subperiods. As in Null Hypotheses I and III, for each portfolio we compute binomial *p*-values based on the number of subperiods on which rejection (using a 5% two-sided criterion) occurs. Rejection of Null Hypothesis VI implies that there is a nonzero PPA contribution to portfolio return autocorrelation; the sign of the PPA effect is determined by the sign of the autocorrelation. In addition, we test the return autocorrelation of each of the ten portfolios

[20] Garcia Blandon (2001) examines the return autocorrelation of the IBEX-35, an index composed of the 35 most liquid Spanish companies. He computes returns on an open-to-close basis. It appears he takes the opening price to be the index value when the market opens, rather than the average of the opening prices of the stocks comprising the index; since some of the stocks in the index will not trade at the market opening, the opening price of the index will involve some stale prices, so NT will not be completely eliminated. Garcia Blandon (2001) finds that the autocorrelation disappears when the index returns are computed on an open-to-close basis; this is analogous to our finding for large firms, but contrasts with our finding for small and medium firms.

over the entire sixteen-year data period (roughly 4,000 return observations per portfolio) and separately over the first (1993-2000) and second (2001-08) halves of our data period (roughly 2,000 return observations per portfolio in each half); we report these autocorrelations, and the associated standard errors.

The computation of the autocorrelation of the open-to-close return of the portfolio allows us to obtain a lower bound on the portion of the conventional daily return autocorrelation attributable to PPA. We calculate the autocovariance of conventional daily (open-to-close) portfolio returns by multiplying the conventional daily (open-to-close) autocorrelation of portfolio returns by the conventional daily (open-to-close) variance of portfolio returns. The residual is defined as the difference of the conventional and open-to-close autocovariances. The autocovariance of open-to-close portfolio returns can only come from PPA, so the ratio of the open-to-close autocovariance to the sum of the absolute values of the open-to-close and residual autocovariances gives a lower bound on the proportion of the autocorrelation that is attributable to PPA.

3.3.2. Second method, ETFs

In the second method, we take our portfolio to be an ETF. ETFs are continuously-traded securities which represent ownership of the stocks in a particular mutual fund or index. Because a mutual fund is valued once a day, and an index is calculated at any given instant by averaging the most recent price of each stock in the index, and some of those prices are stale, the mutual funds and indices are themselves subject to NT.

For example, the quoted value of the S&P 500 index exhibits stale pricing because it is an average of the most recent trade price of the stocks in the index. ETFs are traded continuously and very actively, and the value is updated continuously, rather than with lags arising from intervals between trades of the underlying stocks. At any instant, each stock price is somewhat stale because it has not been adjusted since the last trade, so the index exhibits staleness; however, each trade of the ETF represents an actual trade, which by definition is not stale at the time it occurs. In particular, each trade of the ETF occurs at a price different from the current value of the index; in the absence of PPA, the ETF price should reflect all the information in the market, including the “correct” price of the stocks in the index, even if many of those stocks have not traded for some time.

For this paper, the ETF we choose is SPDRs, an ETF based on the S&P 500 index; each SPDR share represents a claim to one-tenth of the value of the S&P 500 index. Since SPDRs are a single security, NT arises only from days on which no trade occurs; since SPDRs are traded extremely actively, NT makes no contribution to the SPDRs' return autocorrelation. SPDRs are subject to TVRP, but TVRP results in positive autocorrelation, and our SPDR autocorrelations are negative in seven of the eight two-year subperiods. As a single security priced on a grid, SPDRs exhibit BAB.

Before proceeding to the main test, we test whether SPDR autocorrelation can be explained by BAB. In the Roll (1984) model of BAB, the choice of the bid or ask price at each successive trade is given by an IID toss of a fair coin. In that model, assuming the absence of PPA, the autocovariance of percentage returns arising from BAB is equal to minus the mean square spread ratio (MSSR) divided by 4.[21] In practice, it seems likely that the successive coin tosses are positively serially correlated, in which case the autocovariance induced by BAB is smaller in magnitude than MSSR/4. It is only if the successive coin tosses are *negatively* serially correlated that the autocovariance induced by BAB exceeds MSSR/4 in magnitude, but it can never exceed MSSR; that upper bound is achieved only in the extreme case in which the successive coin tosses are deterministic and strictly alternate between heads and tails.

We compute the conventional daily return autocorrelation of the SPDRs; thus, rather than looking at successive trades on a single day, we consider a single trade (the closing trade) on each day. Roll (1984) showed that, in the absence of PPA, the expected autocovariance induced by BAB is independent of the time interval chosen.[22] In this context, it seems likely that the coin tosses associated with the closing prices on different days are uncorrelated or nearly so, and that whatever serial correlation may exist in the coin tosses is likely be positive. Thus, it seems very likely that the autocovariance induced by BAB does not exceed MSSR/4.

Since the Pearson sample autocorrelation coefficient r_p for conventional daily returns is essentially the autocovariance divided by the sample variance σ^2 of conventional daily returns, we correct the Pearson autocorrelation coefficient by adding $\text{MSSR}/4\sigma^2 = (\text{RMSSR}/\sigma)^2/4$, where RMSSR denotes root mean square spread ratio; this eliminates the autocorrelation arising from BAB in case the coin tosses are uncorrelated or positively correlated; we also correct the Pearson autocorrelation coefficient by adding MSSR/σ^2 =

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[21] See Roll (1984), in particular Equation (1) on page 1129, footnote 5 on page 1130, and the sentence preceding that footnote.

[22] See Roll (1984), in particular footnote 4 on page 1130, the sentence preceding that footnote, and part (B) of Appendix A on page 1136.

(RMSSR/σ)^2, which eliminates any autocorrelation that could possibly arise from BAB. We perform *t*-tests on the corrected Pearson autocorrelation coefficients to test whether SPDR return autocorrelation could arise from BAB alone.

Our main test using ETFs is whether the past returns of SPDRs are correlated with the future returns of individual stocks. The daily return of each individual stock is computed in the conventional way. We compute the correlation between the conventional return of stock i on day d+1 (in other words, the return over the return period from the final trade of the stock on day d to the final trade of the stock on day d+1) with the return of the SPDRs over the return period from the time of the last trade of the SPDRs on day d-1 through the time of the last trade of the *stock* on day d. If a stock does not trade on day d or the stock does not trade on day d+1, we omit the data from our calculation.[23]

Note that each time we compute a correlation, it is the correlation of a stock return over a given return period with the return of a traded security, SPDRs, over a disjoint return period, with both the SPDRs and the stock trading in the interval separating the two return periods. Thus, the calculation of the correlation does not use stale prices, and hence there is no NT effect. Since BAB turns out not to be a significant source of return autocorrelation for the SPDRs at the level of two-year time-horizon subperiods (see Table 11), since the stock is a different security from the SPDRs, and since the stock trades occur at different times from the SPDR trades, any BAB between the SPDRs and the individual stock will be virtually eliminated and can be ignored.

Thus, in the absence of PPA, the correlation between the return of the individual stock and the return of the SPDRs must be zero. Our **Null Hypothesis VII** is that the correlation of each of the individual stock returns and the return of the SPDRs is zero in each of the eight two-year time-horizon subperiods. As in Null Hypotheses II and IV, we compute counts of one-sided + and – rejections, as well as two-sided +/- rejections, and test using order statistics (p_3) and the average of p-values (p_4) for all eight two-year time-horizon subperiods, as well as for the four subperiods in the first half of our data period and the four subperiods in the second half. Rejection of Null Hypothesis VII implies that the PPA contributes to portfolio return autocorrelation.

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[23] As above, the reader might have expected us to set the return to zero on days on which the stock does not trade. We chose instead to omit the data for the reasons explained above. Setting the return to zero and including it in the data makes little difference in the results.

Our test detects only that portion of PPA arising from the slow incorporation of the very public, non-firm-specific, information contained in the price of SPDRs into the price of individual firms. The remainder, which presumably constitutes the vast majority of the total PPA present in the market, is not captured by this test.

Ex ante, this seems to us an unlikely place to search for PPA. PPA is usually discussed in the market microstructure literature, and is understood to mean the slow incorporation of private, firm-specific, information into the prices of individual securities. The current price of SPDRs is public, not private. Indeed, because of its link to the closely-watched S&P 500 index, it is one of a handful of the most visible market statistics.

The two studies most closely related to our SPDR tests are Hasbrouck (1996, 2003).[24] Hasbrouck (2003) showed that index futures lead SPDRs in incorporating new information. Hasbrouck (1996) showed that order flows for large individual stocks generated by index futures-based program trading and index arbitrage have price impacts beyond the index futures themselves, but that these are very quickly incorporated; as indicated in his Figure 1, the impact is substantially achieved within two minutes, and completely achieved within three minutes. Indeed, the two-minute effect is quite close to the permanent effect, and the three-minute effect overshoots. Since index futures lead SPDRs, individual stocks should lag SPDRs by a shorter interval.[25]

These relatively short lags seem to us unlikely to result in daily return autocorrelation, for two reasons. First, stock prices are very volatile and it seems likely that the autocorrelation resulting from a three-minute lag would be swamped by the variability over the other 387 minutes of the trading day. Second, the R^2 of overall market returns on the returns of individual stocks is quite low. Since the correlation of SPDRs with individual stocks induced by the lag will be the product of the information revealed in the lag times the R^2, the effect should be very small indeed. To test whether the lags documented by Hasbrouck (1996, 2003) can explain our findings, we rerun our tests for the three largest firm size groups, calculating the SPDR return over a return period ending three minutes before the last trade of the stock.

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[24] Other studies of the incorporation of public information into securities prices, and their relationship to this paper, are discussed in footnote 7.

[25] Note that this does not imply that the stock will trade within two or three minutes of a move of the SPDRs; rather, it indicates that any trade occurring at least three minutes after the SPDR move should be at the correct price and should not exhibit PPA.

Because the definitions underlying Null Hypothesis VII are somewhat complex, we here present a more formal statement of the model.

Assuming closing time is 4:00 p.m., we define the following notation:

$S_{(d,h)i}$ = Price of stock *i* at hour *h* on date *d*,

$\bar{S}_{(d,h)}$ = Price of SPDRs at hour *h* on date *d*,

$h(d,i)$ = Hour of last trade of stock *i* on date *d*,

$\bar{h}(d,i) = \min\{h(d,i), 4:00\,p.m.\}$,

$S_{di} = S_{(d,h(d,i))i}$ (the closing price),

$\bar{S}_d = \bar{S}_{d,4pm}$,

$$r_{di} = \frac{S_{di} - S_{(d-1)i}}{S_{(d-1)i}},$$

$$\bar{r}_d = \frac{\bar{S}_d - \bar{S}_{d-1}}{\bar{S}_{d-1}},$$

where "hour" means the date-stamp time of the transaction, to the hundredth of a second; as noted above, we do make use of some transactions time-stamped after the close of trade at 4:00 p.m., representing the execution of market-on-close orders.

We decompose the daily return of the SPDRs, $\frac{\bar{S}_d - \bar{S}_{d-1}}{\bar{S}_{d-1}}$, into two components, $\frac{\bar{S}_d - \bar{S}_{d,\bar{h}(d,i))}}{\bar{S}_{d-1}}$ and $\frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}$. No stale prices are used in the calculation of $Corr\left(r_{(d+1)i}, \frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}\right)$, the correlation between the return of stock *i* tomorrow and today's return of SPDRs up to the time of the stock *i*'s today's last transaction; note that if the last stock trade is time-stamped 4:10 p.m., representing the execution of a market-on-close order placed before 4:00 p.m., we use the last SPDR trade time-stamped before 4:00 p.m., to ensure there is no overlap in the time intervals; we provide more detail on our determination of the last trade, and our handling of market-on-close orders, in Section 4. These two returns are computed on disjoint return periods separated by trades, as we can see in Fig. 1, so there is no NT effect; for details, see the Appendix. For the reasons given above, BAB can be ignored. In the absence of PPA, the correlation must be zero.

$$Corr\left(r_{(d+1)i}, \frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}} \right) = 0 . \qquad (1)$$

<Insert Fig. 1>

3.4. Testing hypothesis: testing for correlation

Testing each of our Null Hypotheses requires testing whether a correlation or a set of correlations is zero, positive, or negative. We use three test methods: the Pearson correlation test, the modified Pearson correlation test using the Andrews (1991) heteroskedasticity and autoregression consistent (HAC) covariance estimator, and the Kendall τ-test.

- ***Pearson correlation test* (*a parametric test*):** This method tests whether the correlation between two variables is zero, positive, or negative using the Pearson product-moment correlation coefficient, assuming the variables have a bivariate normal distribution. Letting r_p be the Pearson sample correlation coefficient, we apply the Ljung-Box test with h=1; the test statistics are

  $Q = n(n+2)\frac{r_p^2}{n-1} \sim \chi^2$ with one degree of freedom.

- ***Modified Pearson correlation test*:** We use the Andrews modification of the Pearson test, taking into account the possibility that the error terms exhibit heteroskedasticity or autocorrelation. We use the Andrews (1991) HAC covariance estimator to estimate the correlation coefficient and to test whether it is zero, positive, or negative. The test is based on the fact that the *t*-test statistic of the correlation coefficient of the two variables is numerically equal to the *t*-statistic on the regression coefficient of one variable with respect to the other. The HAC covariance is obtained using Andrews' quadratic spectral (QS) kernel with automatic bandwidth selection method.

- ***Kendall τ-test* (*a nonparametric test*):** Stochastic volatility biases the standard errors in the Pearson correlation test. The Kendall τ-test is a nonparametric test that makes no assumptions on the joint distribution of the variables, and is completely immune to the effects of stochastic volatility. Kendall's sample rank correlation coefficient is

$$\hat{\tau} = \frac{2K}{n(n-1)},$$

where $K = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Q\left((X_i, Y_i),(X_j, Y_j)\right)$ and $Q((a,b),(c,d)) = \begin{cases} 1, & if\ (c-a)(d-b) > 0 \\ -1, & if\ (c-a)(d-b) < 0 \end{cases}$. Then the Kendall τ-test statistic is given by

$$T = 3\hat{\tau}\frac{\sqrt{n(n-1)}}{\sqrt{2(2n+5)}} \ \sim \ N(0,1),$$

which is asymptotically normal; the normal provides an excellent approximation provided that $n > 10$.[26]

4. Data

Our data period covers the sixteen calendar years 1993-2008. We divide this into eight two-year time-horizon subperiods: 1993-94, 1995-96, 1997-98, 1999-2000, 2001-02, 2003-04, 2005-06, and 2007-08. Within each two-year subperiod, we obtain a sample of 1,000 firms, stratified into ten groups of 100 stocks each by firm size.

Because our data period contains the market bubble that burst in 2000, one might be concerned about "regression to the max" (Ross (1987), Brown, Goetzmann, and Ross (1995)). These papers point out that if researchers deliberately focus on periods immediately before and after a big local maximum or minimum in securities prices, a sample selection bias arises in the computation of return autocorrelation. For example, the paths of Geometric Brownian Motion exhibit substantial local maxes and mins. If one takes a long history of Geometric Brownian Motion, and computes the autocorrelation only in the time-horizon subperiods in which a large local max or min occurred, then one is likely to find positive autocorrelation that appears statistically significant in those subperiods, as a result of the bias. However, if one selects the data period without regard to local maxes and mins, there is no bias.

We selected our sixteen-year data period based on the data available, and did not deliberately choose to analyze the period including the bubble.[27] Of course, the inadvertent inclusion of the bubble might

[26] See Sheskin (1997), page 633.

[27] SPDRs were not introduced until 1993, so we could not go back before 1993. Since our methodology uses two-year data subperiods, our data period is the sixteen-year period 1993-2008.

have meant that our results would not extend to other periods. Could the inclusion of the bubble have affected our results? No. All of our autocorrelations are computed separately in each of the eight two-year time-horizon subperiods 1993-94, through 2007-08. Only one of those subperiods, 1999-2000, contains a local max or min that stands out in comparison to other time periods. If we restrict attention to the other seven subperiods, very little changes: the *p*-values rise somewhat because less data is being used, but virtually all of our results retain statistical significance.

The samples are obtained using the following criteria, applied separately to each two-year time-horizon subperiod:

- Since our analysis requires firms' market capitalization, we select the sample from the set of common stocks included in both the TAQ database master file and the Center for Research in Security Prices (CRSP) tapes for the subperiod; the trade data comes exclusively from TAQ, while CRSP data is used solely to establish market capitalization.
- We exclude closed-end investment funds and trusts and ETFs, firms for which no transaction occurs for 30 or more consecutive trading days during the two-year period, the fifty smallest by market capitalization determined from CRSP on the last trading day before the beginning of the two-year period, and firms whose closing price from CRSP was less than $2 on the last trading day before the beginning of the two-year period.
- For each stock, we calculate the market capitalization by multiplying the CRSP number of shares outstanding by the CRSP daily closing price (or the average of the bid-ask quotes) on the last trading day preceding the time-horizon subperiod.
- We select 1,000 firms to have market capitalization equally distributed among the whole range of market capitalizations. For example, if the previous screen left 1,333 stocks, we would choose three out of every four stocks. In particular, we would choose the first, second, third, fifth, sixth, seventh, ninth, tenth, eleventh, …., 1329th, 1330th, 1331st, and 1333rd stocks by market capitalization. We divided these 1,000 firms into ten groups, numbered from 1 (smallest market cap) to 10 (largest market cap). The largest stock in the fifth group and the smallest stock in the sixth group are essentially at the median market capitalization.

For each of these 1,000 NYSE-listed firms in a given group and time-horizon subperiod, we obtained transaction data from the TAQ database; we exclude trades that occurred on other exchanges. We manually cleaned the data to remove clearly erroneous prices.[28] We also use transaction data of the SPDRs over the same data period. In the initial part of our data period, SPDRs were traded exclusively on the AMEX; over time, they began to be traded on Nasdaq, and eventually Nasdaq became the predominant trading venue. We use the most active trading venue for the SPDRs: AMEX for 1993-2000, and Nasdaq for 2001-08. We exclude after-hours trades, but include the execution of market-on-close orders.[29]

For our tests of the autocorrelation of the SPDRs corrected for BAB, it is not appropriate to use the market-on-close orders, since these occur at a single price, and the bid-ask spread is zero. Accordingly, for those tests only, we took the closing price to be the price time-stamped closest to 4:00 p.m.; typically, in the later part of our data period, there are 500 or more SPDR transactions time-stamped within a second of 4:00 p.m. For each day, we took the quotes time-stamped 4:00:00 p.m. (i.e. quotes during the one-second period beginning at 4:00 p.m.), computed the spread ratio for each quote, and then averaged these to obtain a daily spread ratio. Over each multi-year data period, we computed the MSSR by averaging the squares of the daily spread ratios.

Table 3 reports descriptive statistics of our 1,000 NYSE-listed sample firms stratified into each of ten groups by market capitalization. The variables are the number of firms, the firms' market capitalization (in millions of dollars; max, mean, and min), average daily mean return and standard deviation, average

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[28] For example, if the TAQ dataset reported successive trades in a stock at prices of $10, $41, $11, we would eliminate the transaction with a reported price of $41.

[29] The TAQ data contains a substantial number of trades time-stamped shortly after 4:00 p.m. Some of these represent late reporting of transactions carried out just before 4:00 p.m. Once those late-reported transactions are settled, market-on-close buy and sell orders are matched against the order book or each other, and executed. The execution of market-on-close orders is marked in the TAQ dataset as a stopped-stock trade and occurs at the same price as the previous trade. We manually examined the data, and found no instance in which the last transaction time-stamped before 4:15 p.m. (other than one marked as after-hours) appeared to be anything other than a late-reported transaction or the execution of market-on-close orders. To check whether a 4:15 p.m. cut-off was too early, we checked one two-year subperiod: out of 673,486 stock-day pairs (1,331 stocks time 506 business days), only 492 (less than one in 1,000) show a trade, other than those clearly marked as after-hours, that occurred after 4:15 p.m. We manually examined those 492 trades, and while some appeared to be late settling of market-on-close orders that should be included in the closing price, all of those were at the same price as the last trade time-stamped before 4:15 p.m. Accordingly, we exclude all trades that were marked as after-hours trades, and take the last transaction price time-stamped before 4:15 p.m.

daily trading volume (in shares), and average number of days on which trade occurs. The figures are first calculated in each of the eight two-year time-horizon subperiods, then averaged over the eight subperiods. Table 3 reflects the broad coverage of the totality of NYSE-listed stocks. The average (over subperiods) of the minimum market capitalization is 96 million dollars, while the average maximum is 276 billion dollars. The Table shows that as the firm size increases, both average trading volume and average trading days increase. Table 3 also reports the mean daily returns of each portfolio, which are monotonically decreasing in firm size, while daily standard deviation is relatively constant across firm size, reflecting a strong small-firm effect.

<Insert Table 3>

5. Empirical results and their implications

5.1. Individual stock returns

5.1.1. Conventional daily return autocorrelation

Table 4 reports results the tests of Null Hypothesis I, that the average daily return autocorrelation is zero in each firm-size group in each of our eight two-year time-horizon subperiods. These results are presented mainly to link our analysis to previous work, in particular Chan (1993), who reports average return autocorrelation. Our main tests of individual stock conventional return autocorrelation are reported in Table 5.

Columns 2-12 of Table 4 report average autocorrelations and standard errors for each of the eight two-year time-horizon subperiods, along with the whole sixteen-year data period, and the first and second halves of the data period; the last three columns report binomial *p*-values for Null Hypothesis I.

Null Hypothesis I, that the average conventional daily return autocorrelation is zero in each of the eight time-horizon subperiods in each group of stocks, is rejected at the 1% level in all ten firm-size groups (0.1% level in eight of the ten groups); in addition, it is rejected in the first half of our data period at the 5% level in six of the ten firm-size groups, and in the second half of our data period at the 0.1% level in all ten firm-size groups. The significant autocorrelations are predominantly positive in the first half; these positive autocorrelations can come only from PPA. All but one of the significant autocorrelations in the second half are negative; these could come from any combination of NT, BAB, or PPA.

<Insert Table 4>

Table 5 reports our main results on individual stock conventional return autocorrelation: the tests for Null Hypothesis II, that each firm's daily return autocorrelation is zero, using the binomial *p*-value p_3. In the model of Chan (1993), the daily return autocorrelation of each individual firm is zero, which is our Null Hypothesis II. Chan does not test Null Hypothesis II, but his results imply its rejection.[30]

Panel A of Table 5 reports results using the Pearson correlation test, while the results using the Andrews and Kendall τ-tests are reported in Panels B and C of Table A1 in the Data Appendix. Columns 2-9 report the counts of firms with statistically significant conventional return autocorrelation in the eight two-year time-horizon subperiods; columns 10-12 report binomial *p*-values derived from these counts, while columns 13-15 report average *p*-values. Null Hypothesis II is rejected at the 5% level or better for all firm size groups using the Pearson test, for nine of ten groups using the Kendall τ-test, and for eight of the ten groups using the Andrews modified Pearson test. The results from the average of *p*-values tests, which are also reported in Tables 5 and A1, are only slightly weaker. The signs of the significant autocorrelations are mixed, with positive outnumbering negative in the first half of our data period, while the significant autocorrelations are overwhelmingly negative in the second half. As above, significant positive autocorrelations can only come from PPA, while significant negative autocorrelations reflect some combination of PPA, BAB, and NT.

<Insert Table 5>

5.1.2. Open-to-close return autocorrelation

Table 6 reports results on average open-to-close return autocorrelation of individual firms, stratified into the ten firm-size groups. Recall that we present results on averages mainly to link our analysis to

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[30] Null Hypothesis II implies Null Hypothesis I. Table I of Chan (1993) reports that the average autocorrelation for all NYSE and AMEX firms was positive and highly significant in the period 1980-84, negative and highly significant in the period 1985-89, and not significant over the entire period 1980-89. He also found that average daily return autocorrelation was negative and highly significant for small firms, not significant for medium firms, and positive and highly significant for large firms in the period 1980-89.

previous work; we consider the individual tests in Table 7 to be our main tests for individual stock open-to-close autocorrelation. As noted above, open-to-close returns are calculated so as to eliminate NT and greatly reduce BAB, so that PPA is the only plausible source of autocorrelation. Columns 2-12 report averages are reported for each of the eight two-year time-horizon subperiods, along with an average for the whole sixteen-year period and the first and second halves of our data period; the last three columns report bionomial *p*-values for the test of Null Hypothesis III.

Null Hypothesis III, that the average autocorrelation of open-to-close returns is zero in each of the eight two-year time-horizon subperiods in each group of stocks, is rejected at the 0.1% level among nine of ten firm-size groups for the whole data period, and at the 5% level or better among nine of ten firm-size groups for both the first and second halves of our data period. The significant autocorrelations are predominantly positive in the first half; all but one of the significant autocorrelations in the second half are negative. As noted in Section 3.2.2, both positive and negative autocorrelations can only come from PPA. If the reader remains skeptical of our assumption that open-to-close individual stock returns are free of BAB, note that every significant autocorrelation in the first half for eight of our ten firm groups is positive, and those cannot possibly come from BAB.

<Insert Table 6>

Panel A of Table 7 reports our main results on individual open-to-close stock returns, using the Pearson correlation test; the results using the Andrews and Kendall τ-tests are presented in Panels A and B of Table A2 in the Data Appendix. Columns 2-9 report the counts of firms with statistically significant open-to-close return autocorrelation in each of the eight two-year time-horizon subperiods. Columns 10-12 report bionomial *p*-values p_3, while columns 13-15 report average *p*-values p_4. We test Null Hypothesis IV, that each firm's open-to-close return autocorrelation is zero, using the bionomial *p*-value p_3. Null Hypothesis IV is rejected at the 5% level or better for all ten of our firm size groups for the Pearson test, for six groups in the Andrews test and for seven groups in the Kendall τ-test. Very similar results are obtained by comparing p_4, the average of the *p*-values to a distribution obtained by Monte Carlo simulation. The significant autocorrelations in the first half of our data period are overwhelmingly positive, while those in the second half are overwhelmingly negative. All reflect PPA. If the reader remains skeptical of our assumption that BAB is eliminated by using open-to-close returns, note that BAB must be negative, so the significant positive autocorrelations cannot result from by BAB.

Finally, we use the methodology described in Section 3.2.3 to provide a lower bound of the identifiable absolute autocovariance of individual stocks arising from PPA in each firm-size group of stocks and each of the eight two-year time-horizon subperiods. In the interests of brevity, we do not report these results in a table. Averaging over the ten firm-size groups within each two-year time-horizon subperiod, our estimates are that at least 55.8% of average individual stock covariance among our 1,000 stocks came from PPA in 1993-94, 53.3% in 1995-96, 61.2% in 1997-98, 57.3% in 1999-2000, 58.1% in 2001-02, 56.5% in 2003-04, 53.3% in 2005-06, and 57.6% in 2007-08. Averaging over the eight two-year time-horizon subperiods within each firm-size group, we estimate that at least 56.7% of individual stock covariance in the group of smallest firms came from PPA over our sixteen-year data period, 59.8% in group 2, 60.0% in group 3, 60.7% in group 4, 59.4% in group 5, 55.7% in group 6, 54.5% in group 7, 53.5% in group 8, 53.8% in group 9, and 52.3% in the group of largest firms. The average over firm size groups is remarkably stable across time periods, and the average over time periods is remarkably stable across firm size groups.

<Insert Table 7>

5.1.3. Summary: individual stock return autocorrelation

PPA must be an important source of the autocorrelation of daily returns of individual stocks. PPA is systematically positive in the first half (1993-2000) of our data period and systematically negative in the second half (2001-2008). This indicates that, while PPA may vary in sign over time, the sign appears to be consistent across periods of several years. Positive PPA autocorrelation reflects slow price adjustment, while negative PPA autocorrelation reflects overshooting. We believe that the sign of PPA is most likely determined by the prevalence of momentum traders in the market, and possibly also by the relative importance of high-frequency trading.

5.2. Portfolio returns

5.2.1. First method, open-to-close returns

Tables 8 and 9 report our results concerning conventional and open-to-close portfolio returns. Columns 2-12 report portfolio return autocorrelation and standard errors for the eight two-year time-horizon subperiods, the whole sixteen-year data period, and the two halves of the data period. The last three columns present binomial *p*-values for conventional and open-to-close portfolio returns.

Null Hypothesis V is that conventional portfolio return autocorrelation is zero in each portfolio and each subperiod. The binomial analysis presented in Table 8 rejects the null hypothesis at the 1% level or better, for all ten portfolios and all eight subperiods using all three correlation tests over the sixteen-year data period 1993-2008. In the first half of our data period, the null hypothesis is rejected at the 0.1% level for all but the largest firm-size portfolio, for all three correlation tests. By contrast, in the second half of our data period, the null hypothesis is not rejected for any portfolio or any correlation test. The portfolio autocorrelations in the single two-year subperiod 2007-08 are negative for all but one firm-size portfolio, with a mixture of significant and insignificant results. Since NT should be positive, this suggests that PPA was significant and negative in 2007-08, presumably as a result of the extreme volatility of that period. Apart from 2007-08, all but one of the significant autocorrelations in the other two-year subperiods are positive. As the firm size becomes larger, the first-order autocorrelation of portfolio return becomes smaller; this is consistent with the previous studies (e.g., Chordia and Swaminathan (2000, Table I on page 917)).

Table 9 presents the results for open-to-close portfolio returns, and our tests of Null Hypothesis VI, that open-to-close portfolio return is zero for each portfolio and each subperiod. The binomial analysis indicates that Null Hypothesis VI is rejected at the 1% or better level for all three correlation tests in eight of the ten portfolios, the two exceptions being the two largest size portfolios; all but one of the 24 rejections is at the 0.1% level. We see a very similar pattern in the first half of our data period, but much weaker autocorrelation in the second half. For individual portfolios and two-year time-horizon subperiods, all the significant autocorrelations are positive, except for 2007-08, where all of the autocorrelations (whether significant or not) are negative. Interestingly, the point estimates for the largest firm-size portfolio are mostly negative, and they are significant and negative over the entire sixteen-year subperiod, but not in the binomial tests based on the eight two-year subperiods. Thus, our results provide strong evidence of PPA in the eight smaller-firm-size portfolios, and some evidence of PPA in the largest-firm-size portfolio.

Using the methodology described in Section 3.2.3, Table 10 provides a lower bound of the identifiable absolute autocovariance of individual stocks arising from PPA in each firm-size group of stocks and each of the eight two-year time-horizon subperiods. Averaging over the ten firm-size groups within each two-year subperiod, the lower bound on the portion of the autocorrelation attributable to PPA ranges from 57.9% (in 2001-02) to 80.2% (in 2007-08) and 86.27% (in 1999-2000). 1999-2000 was a period of rapid growth, peaking in early 2000, followed by a sharp decline; however, 2007-08 saw a sharp decline but no turnaround (the market low occurred in March 2009). This suggests to us that the high level of PPA is more related to market volatility than a regression to the max issue. Averaging over the eight two-year subperiods within each firm-size group, the lower bound ranges from 47.9% (in the group of largest firms) to 80.2% (in the fourth group by firm size).

<Insert Table 8>

<Insert Table 9>

<Insert Table 10>

5.2.2. Second method, ETFs

This method tests whether past SPDR returns predicts future conventional daily return autocorrelation of individual stocks. We begin with a preliminary discussion of the autocorrelation in SPDR returns, and its attribution to BAB and PPA. Table 11 presents the results of our test for autocorrelation of conventional daily SPDR returns, with corrections to eliminate any autocorrelation arising from BAB. In seven of the eight two-year time-horizon subperiods, the SPDRs exhibit negative autocorrelation, but the autocorrelation is statistically significant only in the 2007-08 subperiod. The autocorrelation is negative and statistically significant at the 0.1% level for 2007-08, for the second half of our data period 2001-08, and for the entire data period 1993-2008. We correct for the maximum possible contribution of BAB, by adding $MSSR/\sigma^2 = (RMSSR/\sigma)^2$ to the Pearson correlation coefficient; this makes little difference in the Pearson correlation coefficient, and the results remain significant at the 0.1% level. This indicates that PPA, in the form of overshooting, is the main source of negative autocorrelation in the SPDR returns.

<Insert Table 11>

Our main autocorrelation test using ETFs is Null Hypothesis VII, that the correlation of individual stock and SPDRs returns is zero. As explained above, these correlations are calculated in a way that eliminates NT and virtually eliminates BAB. The results are presented in Tables 12 and A3. Columns 2-9 report the numbers of firms with statistically significant correlation with the SPDRs in each of the eight two-year time-horizon subperiods. Columns 10-12 report the binomial *p*-value p_3, while the last three columns report p_4, an average of *p*-values, which is compared to a Monte Carlo simulation.

Panel A of Table 12 report results using the Pearson correlation test, while Panels B and C of Table

A3 in the Data Appendix report results using the Andrews and Kendall τ-tests. Hypothesis VII is rejected at the 5% or better level for all ten firm-size portfolios using the binomial Pearson and Kendall τ-tests, and for nine of the ten firm-size portfolios using the binomial Andrews test; the same is true of the average *p*-value tests. For both the binomial and average *p*-value tests, the vast majority of the rejections are at the 1% level, and many are at the 0.1% level, with somewhat higher significance levels for the average *p*-value tests.

The significant autocorrelations in individual portfolios and two-year time-horizon subperiods are disproportionately positive in the first half of our data period and disproportionately negative in the second half. All are evidence of PPA.

<Insert Table 12>

As noted above, Hasbrouck (1996, 2003) has documented that prices of ETFs lead prices of the constituent stocks, but the lags are small, not more than three minutes. To test whether these short lags could be explaining our results for large stocks, we reran the tests of Null Hypothesis VII, computing the SPDR return up through the last SPDR trade at least three minutes before the closing trade of the stock, for the three largest-firm-size groups. The results are reported in Table 13. The counts of significant correlations change very little. Seven of the nine binomial tests (three size groups times three correlation tests) as well as eight of the nine average *p*-value tests remain significant; nine out of nine binomial tests and eight out of nine average *p*-value tests are significant over the first half of our data period. We conclude that the lags documented by Hasbrouck cannot explain our findings.

Our evidence for PPA in large firms is considerably stronger in the SPDR tests than in the portfolio open-to-close return tests. The time interval between a stock trade and the last previous SPDR trade is, in the latter part of our data period, a small fraction of a second; in our tests with lagged SPDR data, the time interval is three minutes. By contrast, in the portfolio open-to-close return tests, the time interval between the first trade on day d+1 and the last trade on day d includes an entire overnight period, and it appears that large stock prices do adjust fairly completely to information overnight, reducing but not entirely eliminating the autocorrelation in open-to-close portfolio returns.

<Insert Table 13>

5.2.3. Summary: portfolio return autocorrelation

Our results for portfolio return autocorrelation closely parallel the results for individual stock return autocorrelation. PPA is the major source of the autocorrelation of daily returns of portfolios. Portfolio PPA exhibits a pronounced shift from positive to negative over the course of our data period. SPDRs exhibit negative return autocorrelation, which cannot be explained by BAB and therefore must reflect PPA. Past returns of SPDRs predict future returns of individual stocks, which must reflect PPA. While PPA varies in sign over time, the sign appears to be consistent across periods of several years. We conjecture that the sign of PPA is determined by the prevalence of momentum traders in the market and by the relative importance of high-frequency trading.

6. Concluding remarks

Daily stock return autocorrelation is one of the most visible stylized facts in empirical finance. While the price discovery literature has clearly demonstrated the existence of PPA in the varying speeds of adjustment across different assets, there is no consensus in the previous literature on the relative contributions of NT, BAB, PPA, and TVRP to daily return autocorrelation.

We find compelling evidence that PPA is an important source, and in some cases the main source, of stock return autocorrelation. PPA is an important source of autocorrelation in all of our tests involving small and medium firms, and in most of our tests involving large firms. Our tests cover both individual stock return autocorrelation and portfolio return autocorrelation. We find that PPA is an important source of autocorrelation in SPDRs, a very actively traded ETF.

Our methods for decomposing stock and portfolio return autocorrelation into NT, BAB, PPA, and TVRP are generally applicable. These methods make use of three key ideas: theoretically signing and/or bounding these components; computing returns over disjoint return subperiods separated by a trade to eliminate NT; subdividing our data period into time-horizon subperiods to obtain independent autocorrelation measures. We also develop a technique to determine a lower bound on the proportion of autocorrelation arising from PPA.

We use two methods to eliminate NT. The first method computes correlations of open-to-close returns; this method can be applied to eliminate NT with other types of securities, and on other exchanges. The second method, used in computing the correlation of individual stock returns and SPDRs, computes the return of the SPDRs separately in the periods before and after the final trade of the stock; this method can be used to eliminate NT using any security which, like the SPDRs, is traded nearly continuously.

By dividing our data period into disjoint time-horizon subperiods, we obtain independent tests of the sources of autocorrelation in the different time-horizon subperiods. Aggregating the tests across time-horizon subperiods allows us to increase the statistical power of our tests, and to work around the problem that returns are correlated across stocks. Our methods for aggregating the results of the time-horizon subperiod tests can be applied to other types of securities and other exchanges.

Further research is needed on the following questions:

- To what extent do these findings extend to other markets involving different institutional structures?
- Among the two groups of largest firms, we find strong evidence of PPA among portfolios in our test using SPDRs, but not our tests involving open-to-close returns. The use of open-to-close returns allows us to measure only a portion of the PPA; that portion is large enough to generate statistical significance among small and medium firms, but evidently not among the largest firms. The test involving SPDRs captures a different portion of the PPA. Is there some other way to capture more of the PPA in a single test?
- Our tests indicate that PPA is positive in certain periods and negative in other periods. We argue that this most plausibly reflects variations in the relative numbers of informed and momentum traders. Is there a direct way to test this?
- Risk management measures such as Value-at-Risk (VaR) are computed from the estimated unconditional correlation among assets. The presence of autocorrelation in stock returns suggests that these risk measures should be adjusted, conditional on the price movements of the previous day. If there is persistent positive autocorrelation, then a downward (upward) movement on the previous day should result in an increase (decrease) in the estimated VaR; these effects are reversed if there is persistent negative autocorrelation.

Appendix: derivation of Equation (1)

As we can see in Fig. 1, the daily return of SPDRs at day *d*, $\frac{\bar{S}_d - \bar{S}_{d-1}}{\bar{S}_{d-1}}$, consists of two components,

$\frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}$ (the return of the SPDRs from 4:00 p.m. yesterday (day *d*-1), to time $\bar{h}(d,i)$ today (day *d*)) and $\frac{\bar{S}_d - \bar{S}_{d,\bar{h}(d,i)}}{\bar{S}_{d-1}}$ (the return from time $\bar{h}(d,i)$ today to 4:00 p.m. today).

Here $\bar{h}(d,i)$ is the time of the individual stock *i*'s last transaction on day *d*, but never later than 4:00 p.m. We have the following identity:

$$\frac{\bar{S}_d - \bar{S}_{d-1}}{\bar{S}_{d-1}} = \frac{\bar{S}_d - \bar{S}_{d,\bar{h}(d,i)}}{\bar{S}_{d-1}} + \frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}$$

The usual story for correlation arising from NT goes as follows: Suppose that information affecting the value of the stock *i* becomes known between $\bar{h}(d,i)$ and 4:00 p.m. of day *d* (interval B in Fig. 1). This information will not be reflected in stock *i*'s closing price on day *d*, but will be reflected in price on day *d*+1, and thus in the return, *r*(*d*+1, *i*), *on day* *d*+1. However, the SPDRs trade very frequently, and will usually trade at many times between $\bar{h}(d,i)$ and 4:00 p.m. of day *d*. Consequently, the information will be reflected in the SPDRs' price and return *on day d*. This induces a spurious positive correlation between the SPDRs' return on day *d* and the stock return on day *d*+1.

Our analysis, however, is not dependent on the particular mechanism by which NT induces spurious correlation. The contribution of the NT effect to the correlation between the SPDRs return and the stock return comes solely from the interval B in Fig. 1, where there is an overlap between the time intervals on which the day *d* return of the SPDRs and the day *d*+1 return of stock *i* are computed. Said slightly differently, the return of the stock on day *d*+1 is computed using the price of the stock at the time of its last trade on day *d*, and that price is stale on the interval B in Fig. 1, but is *not* stale at the time $\bar{h}(d,i)$.

$r_{(d+1),i}$ is the return over the intervals B and C. $\frac{\bar{S}_d - \bar{S}_{d-1}}{\bar{S}_{d-1}}$ is the return over the intervals A and B. The correlation comes only from the overlap, interval B. If we eliminate interval B from our return calculation for the SPDRs, the return becomes $\frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}$. In the correlation $Corr\left(r_{(d+1)i}, \frac{\bar{S}_{d,\bar{h}(d,i)} - \bar{S}_{d-1}}{\bar{S}_{d-1}}\right)$, no stale prices are used; if the correlation is not zero, it must be coming from something other than NT. BAB is too small to generate statistically significant autocorrelation. In the absence of PPA, the correlation must be zero, so Equation (1) holds.

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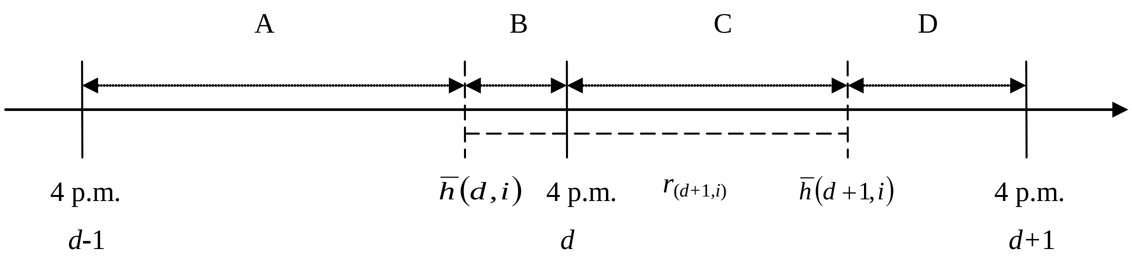

Fig. 1. Time diagram for Null Hypothesis VII. Our Null Hypothesis VII is that the correlation of each of the individual stock returns and the return of the SPDRs is zero. $r_{(d+1,i)}$ is the daily return of each individual stock on day *d*+1, computed in the conventional way. We compute the correlation between the return of stock *i* on day *d*+1 (in other words, the return from the final trade of the stock on day *d* to the final trade of the stock on day *d*+1, corresponding to the intervals B and C) with the return of the SPDRs over the interval from the time of the last trade of the SPDRs on day *d*-1 through the time of the last trade of the *stock* on day *d*, corresponding to the interval A.

Table 1
Signs of conventional daily return autocorrelation from various sources. BAB denotes Bid-Ask Bounce, NT the Nonsynchronous Trading Effect, PPA Partial Price Adjustment, and TVRP Time-Varying Risk Premium.

Source	Individual stock	Portfolio
BAB	-	-/0
NT	-	+
PPA	+/-	+/-
TVRP	+	+

Table 2

Binomial *p*-values combining two-year time-horizon subperiod results, 5% two-sided tests in each subperiod. In each subperiod, we determine whether or not a hypothesis is rejected by a 5% two-sided test. We then count the number of subperiods in which the hypothesis is rejected, and compute the *p*-value from the binomial distribution. For example, the probability that a correct hypothesis is rejected in two of four subperiods is 0.0140.

Number of rejections	*p*-value (Four subperiods)	*p*-value (Eight subperiods)
0	1.0000	1.0000
1	0.1855	0.3366
2	0.0140	0.0572
3	0.0005	0.0058
4	6.25×10^{-6}	0.0004
5	-	1.54×10^{-5}
6	-	4.01×10^{-7}
7	-	5.98×10^{-9}
8	-	3.91×10^{-11}

Table 3

Descriptive statistics of data. We use transaction data from TAQ database over the data period from January 4, 1993 to December 31, 2008, drawing separate samples of firms in each two-year subperiod. All statistics are first calculated in each of the eight two-year time-horizon subperiods, then averaged over the eight subperiods. ¶ denotes the statistics of portfolios, not the average of individual firms of each group.

Portfolio	No. of firms	Market capitalization (in Mil. of dollars)			Daily *portfolio* returns¶		Average daily trading volume (in shares)	Average time interval between the closing trade of individual stock and the closing trade of SPDRs (in seconds)	Average number of days on which trade occurs
		Mean	Min	Max	Mean (%)	Std. dev. (%)			
Smallest	100	166.2	96.0	241.6	0.056	1.191	95,470.3	1,815.4	496.8
2	100	327.4	244.6	415.2	0.050	1.276	173,214.1	1,072.6	501.6
3	100	507.7	416.8	611.4	0.049	1.237	227,023.4	768.5	502.9
4	100	748.0	614.5	901.5	0.035	1.227	278,469.4	615.0	503.2
5	100	1,093.8	905.4	1,312.0	0.046	1.194	394,488.1	443.8	503.6
6	100	1,581.3	1,315.1	1,904.7	0.039	1.136	481,259.1	317.9	503.7
7	100	2,394.2	1,911.9	2,985.2	0.038	1.165	707,722.2	218.7	503.7
8	100	4,076.4	3,001.5	5,558.9	0.042	1.167	1,003,812.0	165.0	503.8
9	100	8,314.0	5,617.0	12,130.5	0.042	1.145	1,677,393.0	122.9	503.7
Largest	100	41,587.5	12,3111.4	276,262.5	0.038	1.185	4,268,534.0	84.1	503.8

Table 4
Average *individual* daily return autocorrelations: conventional daily returns (Null Hypothesis I). Numbers in parenthesis are standard errors. In each time-horizon subperiod, ** and * denote significance at the 1% and 5% two-sided levels, respectively. The final three columns report results of the binomial tests based on counting the number of two-year subperiods in which the average autocorrelation of a given firm-size group is statistically significant at the 5% level.

Portfolio	Average *individual* daily return autocorrelations: conventional daily returns											Binomial *p*-value		
	93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	00-08
Smallest	-0.0330**	-0.0337**	0.0409**	-0.0031	0.0343**	-0.0006	-0.0176*	-0.0678**	-0.0102**	-0.0072	-0.0129**	0.0000	0.0005	0.0005
	(0.0110)	(0.0118)	(0.0110)	(0.0090)	(0.0097)	(0.0090)	(0.0075)	(0.0100)	(0.0037)	(0.0056)	(0.0049)			
2	0.0037	-0.0001	0.0722**	0.0138	-0.0044	-0.0352**	-0.0236**	-0.0562**	-0.0037	0.0224**	-0.0298**	0.0004	0.1855	0.0005
	(0.0114)	(0.0111)	(0.0097)	(0.0092)	(0.0101)	(0.0088)	(0.0072)	(0.0087)	(0.0036)	(0.0054)	(0.0045)			
3	0.0148	0.0155	0.0643**	0.0187*	-0.0312**	-0.0501**	-0.0108	-0.0529**	-0.0040	0.0283**	-0.0362**	0.0000	0.0140	0.0005
	(0.0095)	(0.0096)	(0.0083)	(0.0094)	(0.0109)	(0.0069)	(0.0072)	(0.0090)	(0.0034)	(0.0047)	(0.0044)			
4	0.0315**	-0.0001	0.0600**	-0.0077	-0.0547**	-0.0625**	-0.0270**	-0.0455**	-0.0133**	0.0209**	-0.0474**	0.0000	0.0140	0.0000
	(0.0092)	(0.0095)	(0.0095)	(0.0085)	(0.0089)	(0.0074)	(0.0070)	(0.0098)	(0.0034)	(0.0048)	(0.0042)			
5	0.0183	0.0095	0.0155	-0.0108	-0.0335**	-0.0425**	-0.0057	-0.0257**	-0.0094**	0.0081	-0.0269**	0.0058	0.1855	0.0005
	(0.0093)	(0.0092)	(0.0090)	(0.0079)	(0.0077)	(0.0079)	(0.0060)	(0.0088)	(0.0030)	(0.0045)	(0.0039)			
6	0.0274**	-0.0067	-0.0004	-0.0317**	-0.0164*	-0.0284**	-0.0060	-0.0412**	-0.0129**	-0.0029	-0.0230**	0.0000	0.0140	0.0005
	(0.0070)	(0.0083)	(0.0071)	(0.0078)	(0.0081)	(0.0068)	(0.0056)	(0.0075)	(0.0027)	(0.0039)	(0.0036)			
7	0.0161	-0.0106	0.0084	-0.0204**	-0.0049	-0.0167**	-0.0173**	-0.0397**	-0.0106**	-0.0016	-0.0196**	0.0004	0.1855	0.0005
	(0.0085)	(0.0086)	(0.0075)	(0.0075)	(0.0064)	(0.0062)	(0.0059)	(0.0079)	(0.0027)	(0.0041)	(0.0034)			
8	0.0203**	-0.0121	0.0013	-0.0211**	-0.0001	-0.0241**	-0.0141*	-0.0456**	-0.0119**	-0.0029	-0.0210**	0.0000	0.0140	0.0005
	(0.0070)	(0.0073)	(0.0060)	(0.0067)	(0.0052)	(0.0075)	(0.0061)	(0.0080)	(0.0025)	(0.0035)	(0.0035)			
9	0.0011	0.0038	-0.0002	0.0116	0.0111	-0.0292**	-0.0365**	-0.0672**	-0.0132**	0.0041	-0.0305**	0.0058	1.0000	0.0005
	(0.0068)	(0.0063)	(0.0074)	(0.0060)	(0.0073)	(0.0057)	(0.0055)	(0.0081)	(0.0025)	(0.0033)	(0.0036)			
Largest	-0.0060	0.0045	-0.0288**	0.0112*	-0.0023	-0.0361**	-0.0152*	-0.0804**	-0.0191**	-0.0048	-0.0335**	0.0000	0.0140	0.0005
	(0.0058)	(0.0058)	(0.0067)	(0.0056)	(0.0065)	(0.0070)	(0.0059)	(0.0086)	(0.0025)	(0.0031)	(0.0038)			

Table 5
Autocorrelation of daily *individual* stock returns: conventional daily returns (Null Hypothesis II). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant autocorrelation at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels. Pearson autocorrelation tests are used in Panel A of this table; results using the Andrews test and Kendall τ-test are reported in Panels B and C of Table A1 in the Data Appendix.

Portfolio		Autocorrelation of daily *individual* stock returns: conventional daily returns								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel A: Pearson correlation test															
S	+	12	13	31	19	31	14	6	5	0.0078**	0.0038**	0.1250	0.224**	0.153**	0.294
	-	26	38	15	20	10	14	20	45	0.0000***	0.0015**	0.0078**	0.133***	0.113**	0.152**
	+-	38	51	46	39	41	28	26	50	0.0000***	0.0006***	0.0027**	0.132***	0.117**	0.148**
2	+	26	22	45	17	18	7	3	7	0.0082**	0.0009***	0.6312	0.262**	0.103**	0.422
	-	16	18	6	15	18	26	17	38	0.0000***	0.0603	0.0009***	0.166***	0.220**	0.112**
	+-	42	40	51	32	36	33	20	45	0.0000***	0.0012**	0.0078**	0.144***	0.125**	0.163**
3	+	23	23	38	21	15	0	8	6	0.0222*	0.0004***	0.9766	0.287**	0.101**	0.474
	-	13	12	5	10	28	31	12	34	0.0008***	0.1250	0.0038**	0.200**	0.288	0.113**
	+-	36	35	43	31	43	31	20	40	0.0000***	0.0014**	0.0078**	0.151***	0.140**	0.163**
4	+	30	18	41	11	5	1	7	7	0.0703	0.0053**	1.0000	0.341	0.128**	0.554
	-	10	22	7	21	31	37	18	31	0.0005***	0.0325*	0.0007***	0.151***	0.210**	0.092***
	+-	40	40	48	32	36	38	25	38	0.0000***	0.0012**	0.0032**	0.139***	0.128**	0.151**
5	+	24	23	20	11	6	3	6	9	0.0222*	0.0053**	0.9645	0.314**	0.141**	0.486
	-	15	13	14	16	26	26	8	23	0.0001***	0.0027**	0.0191*	0.163***	0.173**	0.153**
	+-	39	36	34	27	32	29	14	32	0.0001***	0.0024**	0.0325*	0.180***	0.150**	0.211**
6	+	18	15	9	6	9	3	4	4	0.2701	0.0603	0.9645	0.420	0.250**	0.590
	-	5	16	12	23	16	18	8	24	0.0034**	0.1250	0.0191*	0.211**	0.243**	0.178**
	+-	23	31	21	29	25	21	12	28	0.0005***	0.0064**	0.0603	0.228**	0.197**	0.258**
7	+	21	14	18	7	7	4	3	6	0.2701	0.0325*	0.9645	0.378	0.198**	0.558
	-	13	18	11	14	11	15	10	33	0.0000***	0.0053**	0.0078**	0.182***	0.184**	0.180**
	+-	34	32	29	21	18	19	13	39	0.0010***	0.0064**	0.0438*	0.221**	0.178**	0.263
8	+	18	9	3	4	5	3	2	8	1.0000	0.9645	1.0000	0.565	0.469	0.661
	-	7	11	8	15	4	18	11	33	0.0082**	0.0325*	0.1718	0.266**	0.266	0.267
	+-	25	20	11	19	9	21	13	41	0.0181*	0.0854	0.1905	0.308**	0.292	0.325
9	+	7	8	12	10	14	1	2	3	1.0000	0.0325 *	1.0000	0.517	0.282	0.753
	-	9	4	12	4	5	16	13	43	0.0466*	0.3052	0.1056	0.330**	0.434	0.227**
	+-	16	12	24	14	19	17	15	46	0.0018**	0.0603	0.0247*	0.287**	0.324	0.250**
L	+	4	5	4	8	5	3	2	3	1.0000	0.3052	1.0000	0.654	0.516	0.792
	-	7	5	19	6	7	24	14	52	0.0078**	0.1250	0.0325*	0.262**	0.351	0.172**
	+-	11	10	23	14	12	27	16	55	0.0078**	0.1250	0.0603	0.317**	0.382	0.251**

Table 6

Average *individual* daily return autocorrelations: open-to-close returns (Null Hypothesis III). Numbers in parenthesis are standard errors. In each two-year time-horizon subperiod, ** and * denote significance at the 1% and 5% two-sided levels, respectively. The final three columns report *p*-values from the binomial tests based on counting the number of two-year subperiods in which the average autocorrelation of a given firm-size group is statistically significant at the 5% level.

Portfolio	Average *individual* daily return autocorrelations: open-to-close returns											Binomial *p*-value		
	93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	00-08
Smallest	0.009	0.024**	0.057**	0.009	0.028**	0.002	-0.017*	-0.059**	0.007	0.025**	-0.012*	0.0000	0.0140	0.0005
	(0.006)	(0.007)	(0.010)	(0.009)	(0.009)	(0.009)	(0.007)	(0.010)	(0.003)	(0.004)	(0.005)			
2	0.025**	0.029**	0.074**	0.033**	-0.006	-0.031**	-0.028**	-0.052**	0.005	0.040**	-0.029**	0.0000	0.0000	0.0005
	(0.008)	(0.007)	(0.009)	(0.008)	(0.009)	(0.008)	(0.006)	(0.009)	(0.003)	(0.004)	(0.004)			
3	0.035**	0.039**	0.065**	0.033**	-0.034**	-0.046**	-0.012	-0.055**	0.003	0.043**	-0.037**	0.0000	0.0000	0.0005
	(0.007)	(0.008)	(0.008)	(0.009)	(0.009)	(0.005)	(0.007)	(0.009)	(0.003)	(0.004)	(0.004)			
4	0.053**	0.030**	0.062**	0.007	-0.049**	-0.050**	-0.023**	-0.050**	-0.003	0.038**	-0.043**	0.0000	0.0005	0.0000
	(0.008)	(0.007)	(0.009)	(0.008)	(0.008)	(0.007)	(0.007)	(0.009)	(0.003)	(0.004)	(0.004)			
5	0.043**	0.033**	0.022*	0.006	-0.027**	-0.037**	-0.004	-0.025**	0.001	0.026**	-0.023**	0.0000	0.0005	0.0005
	(0.008)	(0.008)	(0.009)	(0.007)	(0.007)	(0.008)	(0.006)	(0.009)	(0.003)	(0.004)	(0.004)			
6	0.053**	0.019**	0.008	-0.010	-0.017*	-0.018**	0.004	-0.035**	0.000	0.017**	-0.017**	0.0000	0.0140	0.0005
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.005)	(0.008)	(0.003)	(0.004)	(0.003)			
7	0.047**	0.016*	0.011	-0.002	-0.007	-0.004	-0.015*	-0.040**	0.001	0.018**	-0.017**	0.0004	0.0140	0.0140
	(0.007)	(0.008)	(0.008)	(0.006)	(0.006)	(0.005)	(0.006)	(0.007)	(0.003)	(0.004)	(0.003)			
8	0.051**	0.010	-0.011	-0.002	0.000	-0.009	-0.002	-0.041**	-0.001	0.012**	-0.013**	0.0572	0.1855	0.1855
	(0.006)	(0.006)	(0.006)	(0.007)	(0.005)	(0.007)	(0.006)	(0.007)	(0.002)	(0.003)	(0.003)			
9	0.019**	0.000	-0.019*	0.013*	0.010	-0.018**	-0.017**	-0.056**	-0.009**	0.003	-0.020**	0.0000	0.0005	0.0005
	(0.006)	(0.007)	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.007)	(0.002)	(0.003)	(0.003)			
Largest	-0.001	-0.019**	-0.056**	0.001	-0.007	-0.033**	-0.005	-0.066**	-0.023**	-0.019**	-0.028**	0.0004	0.0140	0.0140
	(0.006)	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.002)	(0.003)	(0.003)			

Table 7

Autocorrelation of daily *individual* stock returns: open-to-close returns (Null Hypothesis IV). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant autocorrelation at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels. Pearson autocorrelation tests are used in Panel A of this table; results using the Andrews test and Kendall τ-test are reported in Panels B and C of Table A2 in the Data Appendix.

Portfolio		Autocorrelation of daily *individual* stock returns: open-to-close returns								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel A: Pearson correlation test															
Smallest	+	8	17	34	19	24	18	8	11	0.0002***	0.0191*	0.0191*	0.181***	0.166**	0.196**
	-	6	6	5	13	12	14	14	48	0.0078**	0.1250	0.0038**	0.268**	0.381	0.154**
	+-	14	23	39	32	36	32	22	59	0.0004***	0.0325*	0.0053**	0.183***	0.215**	0.152**
2	+	22	19	44	23	14	7	5	7	0.0078**	0.0006***	0.1250	0.225**	0.103**	0.348
	-	5	5	2	8	16	24	16	34	0.0703	1.0000	0.0012**	0.350	0.578	0.123**
	+-	27	24	46	31	30	31	21	41	0.0000***	0.0038**	0.0064**	0.169***	0.166**	0.172**
3	+	21	22	39	24	10	0	4	7	0.2701	0.0004***	1.0000	0.329**	0.100**	0.558
	-	5	5	3	4	29	24	11	42	0.2701	0.9645	0.0053**	0.367	0.615	0.119**
	+-	26	27	42	28	39	24	15	49	0.0002***	0.0027**	0.0247*	0.181***	0.169**	0.193**
4	+	33	22	36	18	6	0	5	8	0.0703	0.0007***	1.0000	0.328**	0.099**	0.557
	-	3	4	3	14	29	29	17	38	0.4651	0.9645	0.0009***	0.357	0.618	0.096***
	+-	36	26	39	32	35	29	22	46	0.0000***	0.0027**	0.0053**	0.158***	0.154**	0.163**
5	+	31	27	22	11	4	7	6	10	0.0222*	0.0053**	0.3052	0.270**	0.129**	0.412
	-	7	6	11	8	18	28	4	24	0.0222*	0.0603	0.0406*	0.284**	0.328	0.239**
	+-	38	33	33	19	22	35	10	34	0.0011**	0.0096**	0.1250	0.214**	0.174**	0.254**
6	+	25	15	12	6	6	9	3	5	0.0703	0.0603	0.9645	0.365	0.223**	0.507
	-	0	7	12	14	13	15	4	24	0.2701	0.6312	0.1056	0.354	0.436	0.272
	+-	25	22	24	20	19	24	7	29	0.0011**	0.0078**	0.2628	0.280**	0.221**	0.340
7	+	29	19	16	8	4	6	2	6	0.2701	0.0191*	1.0000	0.393	0.172**	0.615
	-	5	12	11	9	13	7	11	28	0.0078**	0.1250	0.0325*	0.260**	0.303	0.217**
	+-	34	31	27	17	17	13	13	34	0.0010***	0.0150*	0.0438*	0.250**	0.197**	0.303
8	+	25	10	4	8	5	4	5	6	0.0466*	0.3052	0.3052	0.416	0.322	0.510
	-	2	5	15	9	6	10	3	25	1.0000	1.0000	0.9645	0.443	0.486	0.400
	+-	27	15	19	17	11	14	8	31	0.0386*	0.0247*	0.3052	0.334	0.269	0.399
9	+	10	11	12	7	16	2	3	6	1.0000	0.0325*	1.0000	0.431	0.261**	0.602
	-	4	8	14	3	5	10	11	34	0.2701	0.9645	0.1250	0.375	0.487	0.263
	+-	14	19	26	10	21	12	14	40	0.0078**	0.1250	0.0603	0.306**	0.328	0.284
Largest	+	9	3	4	6	7	0	5	0	1.0000	0.9645	1.0000	0.626	0.538	0.714
	-	5	8	31	7	7	17	8	40	0.0078**	0.1250	0.0325*	0.266**	0.313	0.220**
	+-	14	11	35	13	14	17	13	40	0.0036**	0.0854	0.0438*	0.313**	0.335	0.290

Table 8

First-order autocorrelation of daily *portfolio* returns: conventional daily returns (Null Hypothesis V). Numbers in parenthesis are standard errors, computed for the Pearson, Andrews, and Kendall tests. In each two-year time-horizon subperiod, ** and * denote significance at the 1% and 5% two-sided levels, respectively. The final three columns report *p*-values from the binomial tests based on counting the number of two-year subperiods in which the autocorrelation of a given firm-size portfolio conventional daily return is statistically significant at the 5% level.

Portfolio	First-order autocorrelation of *portfolio* returns: conventional daily returns											Binomial *p*-value		
	93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	00-08
					Panel A: Pearson correlation test									
Smallest	0.221**	0.136**	0.300**	0.231**	0.144**	0.051	0.059	-0.102*	0.008	0.233**	-0.034	0.0000	0.0000	0.0140
2	0.240**	0.142**	0.286**	0.211**	-0.003	0.026	0.009	-0.089*	-0.006	0.232**	-0.049*	0.0000	0.0000	0.1855
3	0.210**	0.212**	0.276**	0.157**	-0.035	0.001	0.019	-0.059	0.009	0.216**	-0.037	0.0004	0.0000	1.0000
4	0.258**	0.174**	0.287**	0.092*	-0.052	-0.027	0.006	-0.023	0.016	0.201**	-0.025	0.0004	0.0000	1.0000
5	0.264**	0.192**	0.211**	0.151**	0.028	0.044	0.073	0.006	0.060**	0.194**	0.023	0.0004	0.0000	1.0000
6	0.258**	0.192**	0.201**	0.085	0.046	0.025	0.083	-0.022	0.048**	0.162**	0.009	0.0058	0.0005	1.0000
7	0.220**	0.170**	0.208**	0.080	0.097*	0.032	0.058	-0.016	0.053**	0.158**	0.020	0.0004	0.0005	0.1855
8	0.217**	0.158**	0.141**	0.111*	0.058	0.006	0.024	-0.028	0.035*	0.144**	-0.001	0.0004	0.0000	1.0000
9	0.139**	0.146**	0.054	0.112*	0.085	-0.041	-0.003	-0.073	0.007	0.098**	-0.026	0.0058	0.0005	1.0000
Largest	0.025	0.115**	-0.003	0.083	0.028	-0.068	-0.054	-0.082	-0.017	0.048*	-0.047*	0.0036	0.1855	1.0000
	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.016)	(0.022)	(0.022)			
					Panel B: Andrews' modified Pearson correlation test									
Smallest	0.256**	0.193**	0.337**	0.234**	0.176**	0.103*	0.069	-0.107	0.046	0.260**	-0.014	0.0000	0.0000	0.0140
	(0.045)	(0.045)	(0.060)	(0.050)	(0.061)	(0.044)	(0.045)	(0.068)	(0.041)	(0.026)	(0.047)			
2	0.275**	0.204**	0.316**	0.213**	0.016	0.066	0.018	-0.091	0.016	0.254**	-0.038	0.0004	0.0000	1.0000
	(0.047)	(0.042)	(0.067)	(0.052)	(0.061)	(0.044)	(0.041)	(0.068)	(0.039)	(0.030)	(0.044)			
3	0.246**	0.294**	0.296**	0.158**	-0.026	0.035	0.030	-0.063	0.031	0.237**	-0.025	0.0004	0.0000	1.0000
	(0.053)	(0.044)	(0.067)	(0.045)	(0.054)	(0.040)	(0.038)	(0.068)	(0.034)	(0.031)	(0.041)			
4	0.281**	0.210**	0.301**	0.093*	-0.045	0.006	0.014	-0.028	0.030	0.213**	-0.017	0.0004	0.0000	1.0000
	(0.050)	(0.043)	(0.062)	(0.040)	(0.056)	(0.042)	(0.043)	(0.065)	(0.033)	(0.031)	(0.040)			
5	0.286**	0.289**	0.235**	0.151**	0.035	0.076	0.084*	0.001	0.079*	0.218**	0.033	0.0000	0.0000	0.1855
	(0.047)	(0.055)	(0.070)	(0.042)	(0.056)	(0.046)	(0.039)	(0.067)	(0.033)	(0.034)	(0.041)			
6	0.275**	0.241**	0.222**	0.084	0.047	0.048	0.097*	-0.027	0.063*	0.176**	0.017	0.0004	0.0005	0.1855
	(0.047)	(0.042)	(0.068)	(0.047)	(0.057)	(0.044)	(0.040)	(0.061)	(0.030)	(0.032)	(0.039)			
7	0.239**	0.236**	0.232**	0.078	0.097	0.060	0.076	-0.023	0.072*	0.176**	0.028	0.0058	0.0005	1.0000
	(0.044)	(0.047)	(0.061)	(0.047)	(0.054)	(0.048)	(0.044)	(0.069)	(0.035)	(0.030)	(0.045)			
8	0.241**	0.200**	0.168**	0.107	0.060	0.034	0.039	-0.033	0.051	0.162**	0.005	0.0058	0.0005	1.0000
	(0.047)	(0.042)	(0.062)	(0.055)	(0.052)	(0.048)	(0.045)	(0.060)	(0.030)	(0.032)	(0.039)			
9	0.148**	0.183**	0.096	0.109*	0.083	-0.021	0.023	-0.078	0.026	0.118**	-0.019	0.0058	0.0005	1.0000
	(0.046)	(0.045)	(0.064)	(0.050)	(0.055)	(0.045)	(0.046)	(0.056)	(0.029)	(0.033)	(0.037)			
Largest	0.036	0.159**	0.046	0.085	0.024	-0.054	-0.036	-0.087	-0.002	0.071*	-0.046	0.0036	0.1855	1.0000
	(0.040)	(0.046)	(0.054)	(0.046)	(0.051)	(0.044)	(0.044)	(0.058)	(0.027)	(0.029)	(0.037)			

Table 8
First-order autocorrelation of daily *portfolio* returns: conventional daily returns (Null Hypothesis V) — Continued

Panel C: Kendall τ-test														
Smallest	0.132**	0.074*	0.205**	0.163**	0.068*	0.019	0.030	-0.089**	0.055**	0.150**	-0.003	0.0000	0.0000	0.0140
2	0.158**	0.094**	0.217**	0.140**	-0.011	0.008	0.006	-0.071*	0.044**	0.158**	-0.021	0.0000	0.0000	0.1855
3	0.132**	0.143**	0.196**	0.120**	-0.013	-0.014	0.012	-0.062*	0.042**	0.153**	-0.022	0.0000	0.0000	0.1855
4	0.159**	0.119**	0.224**	0.076*	-0.026	-0.031	0.001	-0.043	0.039**	0.151**	-0.026	0.0004	0.0000	0.1855
5	0.170**	0.154**	0.189**	0.099**	0.025	0.020	0.046	-0.011	0.071**	0.154**	0.019	0.0004	0.0000	0.1855
6	0.171**	0.139**	0.163**	0.051	0.050	0.016	0.047	-0.017	0.066**	0.126**	0.024	0.0058	0.0005	0.1855
7	0.146**	0.142**	0.168**	0.071*	0.069*	0.021	0.031	-0.001	0.073**	0.134**	0.031*	0.0000	0.0000	0.1855
8	0.130**	0.118**	0.126**	0.051	0.063*	-0.013	0.007	-0.015	0.053**	0.106**	0.013	0.0004	0.0005	0.0140
9	0.090**	0.090**	0.077**	0.051	0.072*	-0.042	-0.022	-0.062*	0.026*	0.075**	-0.011	0.0000	0.0005	0.0140
Largest	0.011	0.065*	0.042	0.036	0.024	-0.064*	-0.038	-0.070*	0.001	0.041**	-0.034*	0.0058	0.1855	0.0140
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.011)	(0.015)	(0.015)			

Table 9

First-order autocorrelation of daily *portfolio* returns: open-to-close returns (Null Hypothesis VI). Numbers in parenthesis are standard errors. In each two-year time-horizon subperiod, ** and * denote significance at the 1% and 5% two-sided levels, respectively. The final three columns report *p*-values from the binomial tests based on counting the number of two-year subperiods in which the autocorrelation of a given firm-size portfolio daily open-to-close return is statistically significant at the 5% level.

Portfolio	First-order autocorrelation of daily portfolio returns: open-to-close returns											Binomial *p*-value		
	93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	00-08
Panel A: Pearson Correlation Test														
Smallest	0.165**	0.126**	0.249**	0.215**	0.124**	0.043	0.054	-0.120**	-0.010	0.211**	-0.048*	0.0000	0.0000	0.0140
2	0.211**	0.164**	0.261**	0.215**	-0.013	0.026	0.004	-0.098*	-0.015	0.232**	-0.055*	0.0000	0.0000	0.1855
3	0.171**	0.232**	0.249**	0.180**	-0.050	-0.001	0.010	-0.087	-0.008	0.214**	-0.056*	0.0004	0.0000	1.0000
4	0.229**	0.212**	0.300**	0.107*	-0.061	-0.018	0.009	-0.045	0.007	0.211**	-0.038	0.0004	0.0000	1.0000
5	0.218**	0.208**	0.203**	0.180**	0.018	0.030	0.055	-0.010	0.050**	0.196**	0.008	0.0004	0.0000	0.1855
6	0.225**	0.209**	0.165**	0.124**	0.022	0.025	0.084	-0.027	0.043**	0.161**	0.001	0.0004	0.0000	0.1855
7	0.195**	0.156**	0.181**	0.132**	0.064	0.034	0.069	-0.048	0.034*	0.160**	-0.006	0.0004	0.0000	0.1855
8	0.187**	0.122**	0.062	0.165**	0.054	0.010	0.062	-0.045	0.023	0.123**	-0.009	0.0058	0.0005	1.0000
9	0.079	0.053	-0.034	0.136**	0.063	-0.031	0.030	-0.086	-0.008	0.055*	-0.033	0.3366	0.1855	1.0000
Largest	-0.041	-0.029	-0.101	0.068	0.000	-0.075	-0.024	-0.109*	-0.052**	-0.017	-0.069**	0.0058	0.1855	0.1855
	(0.045)	(0.044)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)	(0.016)	(0.022)	(0.022)			
Panel B: Andrews' modified Pearson correlation test														
Smallest	0.214**	0.279**	0.424**	0.217**	0.185**	0.063	0.053	-0.126*	0.026	0.293**	-0.042	0.0000	0.0000	0.0140
	(0.040)	(0.042)	(0.089)	(0.050)	(0.056)	(0.043)	(0.046)	(0.064)	(0.040)	(0.032)	(0.045)			
2	0.284**	0.279**	0.321**	0.236**	0.020	0.042	0.004	-0.097	-0.001	0.275**	-0.053	0.0004	0.0000	1.0000
	(0.050)	(0.042)	(0.082)	(0.057)	(0.055)	(0.044)	(0.044)	(0.063)	(0.036)	(0.035)	(0.041)			
3	0.208**	0.350**	0.305**	0.181**	-0.034	0.012	0.010	-0.091	0.006	0.265**	-0.054	0.0004	0.0000	1.0000
	(0.045)	(0.039)	(0.098)	(0.052)	(0.051)	(0.039)	(0.042)	(0.067)	(0.035)	(0.041)	(0.040)			
4	0.254**	0.262**	0.323**	0.109*	-0.043	-0.004	0.008	-0.049	0.015	0.229**	-0.036	0.0004	0.0000	1.0000
	(0.045)	(0.040)	(0.079)	(0.050)	(0.051)	(0.042)	(0.045)	(0.066)	(0.033)	(0.037)	(0.040)			
5	0.246**	0.336**	0.236*	0.178**	0.033	0.041	0.054	-0.013	0.061	0.233**	0.011	0.0004	0.0000	1.0000
	(0.045)	(0.047)	(0.092)	(0.054)	(0.049)	(0.043)	(0.043)	(0.066)	(0.032)	(0.043)	(0.040)			
6	0.236**	0.262**	0.215*	0.126*	0.032	0.037	0.086	-0.030	0.052	0.179**	0.006	0.0004	0.0000	1.0000
	(0.046)	(0.040)	(0.090)	(0.053)	(0.053)	(0.042)	(0.045)	(0.064)	(0.031)	(0.040)	(0.039)			
7	0.201**	0.218**	0.212*	0.132*	0.067	0.047	0.072	-0.050	0.040	0.178**	-0.005	0.0004	0.0000	1.0000
	(0.046)	(0.048)	(0.092)	(0.053)	(0.049)	(0.042)	(0.045)	(0.066)	(0.034)	(0.041)	(0.043)			
8	0.199**	0.179**	0.083	0.169**	0.070	0.020	0.061	-0.046	0.029	0.144**	-0.007	0.0004	0.0005	1.0000
	(0.046)	(0.046)	(0.082)	(0.058)	(0.048)	(0.040)	(0.045)	(0.057)	(0.030)	(0.043)	(0.037)			
9	0.076	0.103*	0.029	0.135*	0.071	-0.019	0.036	-0.090	0.002	0.087*	-0.030	0.0572	0.0140	1.0000
	(0.046)	(0.049)	(0.075)	(0.054)	(0.059)	(0.040)	(0.045)	(0.050)	(0.026)	(0.042)	(0.033)			
Largest	-0.041	0.043	-0.052	0.068	0.004	-0.060	-0.023	-0.111*	-0.044	0.007	-0.067*	0.3366	1.0000	0.1855
	(0.041)	(0.054)	(0.058)	(0.052)	(0.049)	(0.042)	(0.045)	(0.048)	(0.024)	(0.035)	(0.031)			

Table 9
First-order autocorrelation of daily *portfolio* returns: open-to-close returns (Null Hypothesis VI) — Continued

							Panel C: Kendall τ-test							
Smallest	0.103**	0.068*	0.197**	0.151**	0.057	0.013	0.027	-0.088**	0.051**	0.145**	-0.002	0.0000	0.0000	0.1855
2	0.135**	0.111**	0.217**	0.140**	-0.007	0.008	-0.001	-0.061*	0.051**	0.164**	-0.013	0.0000	0.0000	0.1855
3	0.109**	0.147**	0.199**	0.119**	-0.019	-0.019	-0.005	-0.059*	0.040**	0.150**	-0.023	0.0000	0.0000	0.1855
4	0.144**	0.121**	0.241**	0.070*	-0.019	-0.024	-0.004	-0.048	0.043**	0.153**	-0.021	0.0004	0.0000	1.0000
5	0.138**	0.144**	0.205**	0.102**	0.024	0.010	0.032	-0.030	0.067**	0.155**	0.010	0.0004	0.0000	1.0000
6	0.146**	0.136**	0.165**	0.076*	0.038	0.012	0.040	-0.014	0.067**	0.129**	0.022	0.0004	0.0000	1.0000
7	0.132**	0.129**	0.169**	0.109**	0.046	0.016	0.032	-0.029	0.067**	0.138**	0.016	0.0004	0.0000	1.0000
8	0.107**	0.081**	0.099**	0.083**	0.055	0.001	0.027	-0.047	0.048**	0.098**	0.009	0.0004	0.0000	1.0000
9	0.040	0.029	0.028	0.054	0.042	-0.024	-0.002	-0.072*	0.009	0.041**	-0.015	0.3366	1.0000	0.1855
Largest	-0.030	-0.012	-0.050	0.032	0.010	-0.055	-0.028	-0.085**	-0.026*	-0.010	-0.039**	0.3366	1.0000	0.1855
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.011)	(0.015)	(0.015)			

Table 10

Lower bound on proportion of PPA in the autocorrelation of the portfolio returns. The lower bound on the proportion of PPA in the autocorrelation of the portfolio returns is computed as specified in Section 3.2.3.

Portfolio	Open-to-close return autocovariance as percentage of open-to-close plus residual return autocovariance									
	93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	Avg. 93-08	Avg. 93-00	Avg. 01-08
Smallest	0.5888	0.6472	0.6276	0.7577	0.7163	0.7053	0.7962	0.9930	0.7290	0.6553	0.8027
2	0.6487	0.8534	0.7175	0.8609	0.5753	0.8718	0.4172	0.9121	0.7321	0.7701	0.6941
3	0.6245	0.7853	0.7367	0.9724	0.8592	0.3576	0.4461	0.8496	0.7039	0.7797	0.6281
4	0.6989	0.8749	0.7954	0.9732	0.9597	0.5797	0.8033	0.7283	0.8017	0.8356	0.7678
5	0.6385	0.7594	0.7311	0.9933	0.5311	0.5780	0.6423	0.3631	0.6546	0.7806	0.5286
6	0.6498	0.7784	0.6271	0.8556	0.3714	0.8554	0.8450	0.9408	0.7404	0.7277	0.7531
7	0.6758	0.6568	0.6744	0.8023	0.5065	0.8649	0.9769	0.6380	0.7245	0.7023	0.7466
8	0.6702	0.5600	0.3394	0.9051	0.7008	0.7938	0.6523	0.8380	0.6824	0.6187	0.7462
9	0.4311	0.2649	0.2472	0.9131	0.5677	0.6203	0.4716	0.8212	0.5421	0.4641	0.6202
Largest	0.3565	0.1428	0.5097	0.5933	0.0051	0.9258	0.3588	0.9402	0.4790	0.4006	0.5574
Average	0.5983	0.6323	0.6006	0.8627	0.5793	0.7153	0.6410	0.8024			

Table 11

SPDR autocorrelation. Exchange: A denotes AMEX, N Nasdaq; we use the exchange with the highest SPDR volume during the regular trading session; this was initially AMEX, but shifted to Nasdaq during 2001-02. RMSSR is the root mean square spread ratio. The effect of BAB on the Pearson correlation coefficient cannot exceed $(RMSSR/\sigma)^2$, and should generally be much lower. For example, in the Roll (1984) model, the effect of BAB on the Pearson correlation coefficient is the $(RMSSR/\sigma)^2$, divided by four.

Year	Exchange	No. of obs.	Pearson acf	*t*-value	Std. dev. σ (%)	RMSSR (%)	$(RMSSR/\sigma)^2$	Pearson corrected for BAB by $(RMSSR/\sigma)^2$ (Upper bound on BAB)	*t*-value	Pearson corrected for BAB by $(RMSSR/\sigma)^2/4$ (Roll's model)	*t*-value
1993-94	A	486	-0.039	-0.86	0.6291	0.0682	0.01175	-0.027	-0.60	-0.036	-0.76
1995-96	A	506	0.026	0.58	0.6794	0.1013	0.02223	0.048	1.08	0.032	0.71
1997-98	A	505	-0.074	-1.66	1.2669	0.1556	0.01509	-0.059	-1.32	-0.070	-1.58
1999-00	A	504	-0.014	-0.31	1.2973	0.1330	0.01051	-0.003	-0.08	-0.011	-0.25
2001-02	A&N	500	-0.017	-0.38	1.5264	0.0962	0.00397	-0.013	-0.29	-0.016	-0.36
2003-04	N	504	-0.086	-1.93	0.9062	0.1443	0.02536	-0.061	-1.36	-0.080	-1.79
2005-06	N	503	-0.046	-1.03	0.6387	0.0555	0.00755	-0.038	-0.86	-0.044	-0.99
2007-08	N	504	-0.146	-3.30***	1.9036	0.0199	0.00011	-0.146	-3.30***	-0.146	-3.30***
1993-2008		4,012	-0.067	-4.25***	1.1922	0.1083	0.00825	-0.059	-3.73***	-0.065	-4.12**
1993-2000		2,001	-0.033	-1.48	1.0210	0.1195	0.01370	-0.019	-0.86	-0.030	-1.32
2001-2008		2,011	-0.089	-4.00***	1.3403	0.0940	0.00492	-0.084	-3.78***	-0.088	-3.95***

Table 12

ETFs (Null Hypothesis VII). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant correlation with the prior SPDR return at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels. Pearson autocorrelation tests are used in Panel A of this table; results using the Andrews test and Kendall τ-test are reported in Table A3 in the Data Appendix.

Portfolio		Correlation of daily *individual* stock returns and SPDRs								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
		Panel A: Pearson correlation test								p_3	p_3	p_3	p_4	p_4	p_4
Smallest	+	14	18	30	11	15	10	20	5	0.0008***	0.0053**	0.1250	0.209**	0.157**	0.260**
	-	0	1	1	0	3	8	7	41	1.0000	1.0000	0.6312	0.695	1.000	0.391
	+-	14	19	31	11	18	18	27	46	0.0036**	0.0854	0.0119*	0.261**	0.309	0.212**
2	+	22	21	33	13	7	3	4	6	0.2701	0.0027**	0.9645	0.342	0.125**	0.558
	-	0	2	1	0	14	9	7	37	1.0000	1.0000	0.0325*	0.610	1.000	0.220**
	+-	22	23	34	13	21	12	11	43	0.0036**	0.0438*	0.0854	0.275**	0.244**	0.306
3	+	30	33	30	18	6	6	8	7	0.0018**	0.0007***	0.0603	0.236**	0.095***	0.376
	-	2	0	5	2	18	11	8	45	1.0000	1.0000	0.0191*	0.529	0.875	0.184**
	+-	32	33	35	20	24	17	16	52	0.0002***	0.0078**	0.0191*	0.201**	0.175**	0.228**
4	+	29	31	34	16	6	4	6	8	0.0222*	0.0012**	0.3052	0.271**	0.099**	0.443
	-	0	0	2	7	15	11	12	36	1.0000	1.0000	0.0053**	0.504	0.839	0.168**
	+-	29	31	36	23	21	15	18	44	0.0003***	0.0045**	0.0247*	0.207**	0.172**	0.241**
5	+	35	29	29	18	11	8	17	10	0.0002***	0.0007***	0.0191*	0.165***	0.096***	0.234**
	-	0	0	9	6	14	10	2	28	1.0000	1.0000	0.2266	0.527	0.674	0.379
	+-	35	29	38	24	25	18	19	38	0.0001***	0.0038**	0.0119*	0.191***	0.164**	0.218**
6	+	41	27	29	12	10	8	15	11	0.0002***	0.0038**	0.0191*	0.176***	0.112**	0.239**
	-	0	1	6	11	6	6	2	17	1.0000	1.0000	0.9766	0.578	0.661	0.495
	+-	41	28	35	23	16	14	17	28	0.0005***	0.0045**	0.0325*	0.225**	0.165**	0.286
7	+	37	35	36	15	20	5	14	14	0.0001***	0.0015**	0.0850	0.170***	0.094***	0.246**
	-	0	0	3	13	1	2	3	21	1.0000	1.0000	1.0000	0.747	0.756	0.738
	+-	37	35	39	28	21	7	17	35	0.0023**	0.0020**	0.3622	0.247**	0.146**	0.347
8	+	28	31	26	9	19	4	5	11	0.0466*	0.0119*	0.3052	0.253**	0.136**	0.371
	-	0	0	9	15	1	4	3	30	1.0000	1.0000	1.0000	0.623	0.611	0.635
	+-	28	31	35	24	20	8	8	41	0.0466*	0.0038**	0.3052	0.289**	0.173**	0.405
9	+	25	32	14	16	14	1	3	5	1.0000	0.0020**	1.0000	0.378	0.128**	0.628
	-	3	0	12	22	4	15	8	34	1.0000	1.0000	0.3052	0.417	0.539	0.294
	+-	28	32	26	38	18	16	11	39	0.0034**	0.0027**	0.0854	0.229**	0.165**	0.293
Largest	+	12	27	8	10	5	0	1	7	1.0000	0.0191*	1.0000	0.465	0.216**	0.714
	-	4	0	16	16	4	28	10	47	0.2701	1.0000	0.2266	0.369	0.484	0.254**
	+-	16	27	24	26	9	28	11	54	0.0181*	0.0191*	0.1905	0.272**	0.225**	0.320

Table 13

ETFs: large firms only, lag at least three minutes (Null Hypothesis VII). This Table repeats the analysis of Table 12 for the three largest firm-size groups, but requires the SPDR trade to be at least 3 minutes prior to the closing trade of the stock. We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant correlation with the prior SPDR return at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels.

Portfolio		Correlation of daily *individual* stock returns and SPDRs								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel A: Pearson correlation test															
8	+	28	30	25	8	17	4	5	7	0.0466*	0.0154*	0.3052	0.277**	0.146**	0.407
	-	0	0	11	17	1	5	2	35	1.0000	1.0000	1.0000	0.618	0.594	0.643
	+-	28	30	36	25	18	9	7	42	0.1343	0.0032**	0.5206	0.294**	0.171**	0.417
9	+	26	27	13	16	13	2	3	6	1.0000	0.0027**	1.0000	0.372	0.134**	0.611
	-	3	0	12	23	4	18	9	39	1.0000	1.0000	0.3052	0.407	0.538	0.276
	+-	29	27	25	39	17	20	12	45	0.0018**	0.0032**	0.0603	0.220**	0.171**	0.268
Largest	+	11	23	9	11	4	0	0	6	1.0000	0.0119*	1.0000	0.485	0.210**	0.760
	-	5	0	16	18	5	29	10	55	0.0703	1.0000	0.1250	0.335	0.449	0.220**
	+-	16	23	25	29	9	29	10	61	0.0181*	0.0191*	0.1905	0.277**	0.226**	0.327
Panel B: Andrews' modified Pearson correlation test															
8	+	27	35	19	8	14	4	6	2	0.2701	0.0191*	1.0000	0.354	0.152**	0.555
	-	0	0	6	16	1	5	2	21	1.0000	1.0000	1.0000	0.649	0.643	0.655
	+-	27	35	25	24	15	9	8	23	0.0466*	0.0038**	0.3052	0.308**	0.184**	0.433
9	+	26	34	11	17	8	1	4	1	1.0000	0.0053**	1.0000	0.435	0.136**	0.734
	-	2	0	10	23	3	14	7	29	1.0000	1.0000	0.6312	0.477	0.590	0.364
	+-	28	34	21	40	11	15	11	30	0.0036**	0.0064**	0.0854	0.262**	0.172**	0.352
Largest	+	12	29	10	12	1	0	0	5	1.0000	0.0078**	1.0000	0.532	0.188**	0.875
	-	3	0	8	18	4	25	7	44	1.0000	1.0000	0.3052	0.428	0.571	0.285
	+-	15	29	18	30	5	25	7	49	0.5692	0.0247*	1.0000	0.371	0.238**	0.504
Panel C: Kendall τ-test															
8	+	32	30	43	7	20	4	4	3	0.2701	0.0090**	0.9645	0.348	0.144**	0.552
	-	1	2	8	17	0	12	4	30	1.0000	1.0000	1.0000	0.547	0.615	0.479
	+-	33	32	51	24	20	16	8	33	0.0034**	0.0038**	0.3052	0.244**	0.154**	0.335
9	+	24	29	26	17	18	1	3	0	1.0000	0.0009***	1.0000	0.426	0.108**	0.743
	-	2	0	9	25	8	31	10	51	1.0000	1.0000	0.0191*	0.384	0.594	0.173**
	+-	26	29	35	42	26	32	13	51	0.0001***	0.0027**	0.0438*	0.182***	0.157**	0.208**
Largest	+	13	19	24	14	9	0	0	1	1.0000	0.0027**	1.0000	0.486	0.152**	0.819
	-	4	0	3	15	8	40	13	58	1.0000	1.0000	0.0191*	0.404	0.656	0.153**
	+-	17	19	27	29	17	40	13	59	0.0010***	0.0150*	0.0438*	0.225**	0.229**	0.222**

Data Appendix

Table A1

Autocorrelation of daily *individual* stock returns: conventional daily returns (Null Hypothesis II); Supplement to Table 5. This Table supplements Table 5, whose Panel A reported the Pearson autocorrelation test, by reporting the Andrews test (Panel B) and Kendall τ-test (Panel C). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant autocorrelation at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels.

Portfolio		Autocorrelation of daily *individual* stock returns: conventional daily returns								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel B: Andrews' modified Pearson correlation test															
S	+	6	10	24	11	25	8	2	1	1.0000	0.0603	1.0000	0.426	0.250^{**}	0.603
	-	22	31	8	13	7	12	13	29	0.0005^{***}	0.0191^{*}	0.0325^{*}	0.193^{***}	0.175^{**}	0.211^{**}
	+-	28	41	32	24	32	20	15	30	0.0003^{***}	0.0038^{**}	0.0247^{*}	0.196^{***}	0.166^{**}	0.227^{**}
2	+	22	21	37	12	12	6	4	1	0.2701	0.0038^{**}	1.0000	0.345	0.127^{**}	0.563
	-	15	15	4	9	11	21	15	24	0.0015^{**}	0.3052	0.0053^{**}	0.232^{**}	0.309	0.154^{**}
	+-	37	36	41	21	23	27	19	25	0.0000^{***}	0.0064^{**}	0.0096^{**}	0.187^{***}	0.159^{**}	0.216^{**}
3	+	19	19	25	19	11	0	8	0	1.0000	0.0006^{***}	1.0000	0.379	0.124^{**}	0.635
	-	9	8	3	5	26	20	9	23	0.0703	0.9645	0.0119^{*}	0.316^{**}	0.481	0.152^{**}
	+-	28	27	28	24	37	20	17	23	0.0001^{***}	0.0038^{**}	0.0150^{*}	0.206^{**}	0.188^{**}	0.224^{**}
4	+	28	13	36	8	5	1	4	3	1.0000	0.0191^{*}	1.0000	0.453	0.166^{**}	0.740
	-	10	14	5	13	23	32	10	23	0.0008^{***}	0.1250	0.0078^{**}	0.208^{**}	0.280	0.136^{**}
	+-	38	27	41	21	28	33	14	26	0.0005^{***}	0.0064^{**}	0.0325^{*}	0.195^{***}	0.169^{**}	0.220^{**}
5	+	23	17	11	8	5	1	4	6	0.2701	0.0191^{*}	1.0000	0.417	0.199^{**}	0.635
	-	13	12	11	10	16	20	5	11	0.0008^{***}	0.0078^{**}	0.1250	0.236^{**}	0.219^{**}	0.252^{**}
	+-	36	29	22	18	21	21	9	17	0.0023^{**}	0.0119^{*}	0.1905	0.268^{**}	0.204^{**}	0.331
6	+	16	11	7	4	4	2	4	2	1.0000	0.3052	1.0000	0.577	0.341	0.813
	-	4	13	6	14	10	15	4	15	0.0466^{*}	0.3052	0.2266	0.328^{**}	0.353	0.302
	+-	20	24	13	18	14	17	8	17	0.0132^{*}	0.0438^{*}	0.3052	0.336	0.280	0.393
7	+	20	15	12	4	5	5	2	0	1.0000	0.1334	1.0000	0.516	0.281	0.750
	-	11	16	6	9	7	9	10	25	0.0018^{**}	0.0603	0.0325^{*}	0.258^{**}	0.269	0.246^{**}
	+-	31	31	18	13	12	14	12	25	0.0018^{**}	0.0438^{*}	0.0603	0.297^{**}	0.246^{**}	0.348
8	+	15	8	0	3	1	3	2	2	1.0000	1.0000	1.0000	0.768	0.578	0.958
	-	4	11	3	12	3	13	7	21	0.4651	0.9645	0.6312	0.424	0.473	0.375
	+-	19	19	3	15	4	16	9	23	1.0000	0.5185	1.0000	0.493	0.465	0.521
9	+	7	6	8	7	9	0	2	0	1.0000	0.0603	1.0000	0.590	0.361	0.819
	-	7	4	7	5	5	14	8	31	0.0466^{*}	0.3052	0.1250	0.364	0.460	0.268
	+-	14	10	15	12	14	14	10	31	0.0078^{**}	0.1250	0.1250	0.373	0.402	0.344
L	+	4	9	2	9	3	2	3	1	1.0000	1.0000	1.0000	0.731	0.545	0.917
	-	3	3	11	4	5	17	10	39	0.4651	0.9645	0.1250	0.435	0.630	0.240^{**}
	+-	7	12	13	13	8	19	13	40	0.1355	0.5206	0.3052	0.412	0.475	0.349

Table A1

Autocorrelation of daily *individual* stock returns: conventional daily returns (Null Hypothesis II); Supplement to Table 5 — Continued

Panel C: Kendall τ-test

S	+	2	11	27	15	24	10	4	0	1.0000	0.1718	1.0000	0.433	0.372	0.495
	-	42	53	20	22	13	19	16	49	0.0000***	0.0005***	0.0027**	0.110***	0.086***	0.133**
	+-	44	64	47	37	37	29	20	49	0.0000***	0.0007***	0.0078**	0.137***	0.108**	0.165**
2	+	16	19	41	21	10	5	6	3	0.0703	0.0012**	0.9645	0.308**	0.117**	0.500
	-	26	26	6	15	20	29	20	32	0.0000***	0.0603	0.0005***	0.149***	0.194**	0.104**
	+-	42	45	47	36	30	34	26	35	0.0000***	0.0007***	0.0027**	0.141***	0.119**	0.162**
3	+	25	22	38	21	7	2	3	2	1.0000	0.0004***	1.0000	0.449	0.100**	0.798
	-	20	20	7	6	28	32	14	33	0.0018**	0.0603	0.0020**	0.181***	0.256**	0.105**
	+-	45	42	45	27	35	34	17	35	0.0001***	0.0024**	0.0150*	0.157***	0.132**	0.182**
4	+	27	21	42	9	2	0	5	3	1.0000	0.0119*	1.0000	0.485	0.137**	0.833
	-	14	25	7	19	36	43	18	29	0.0001***	0.0325*	0.0007***	0.140***	0.192**	0.088***
	+-	41	46	49	28	38	43	23	32	0.0000***	0.0020**	0.0045***	0.142***	0.128**	0.155**
5	+	26	15	21	15	4	3	4	8	0.2701	0.0015**	0.9645	0.368	0.137**	0.599
	-	21	23	12	12	24	26	10	16	0.0000***	0.0038**	0.0078**	0.156***	0.161**	0.152**
	+-	47	38	33	27	28	29	14	24	0.0002***	0.0024**	0.0325*	0.186***	0.144**	0.229**
6	+	18	12	10	4	4	2	5	2	1.0000	0.2266	1.0000	0.543	0.306	0.781
	-	11	20	12	22	19	18	6	9	0.0015**	0.0053**	0.0603	0.205**	0.169**	0.241**
	+-	29	32	22	26	23	20	11	11	0.0036**	0.0053**	0.0854	0.266**	0.187**	0.344
7	+	20	15	11	4	6	2	5	5	0.2701	0.1718	1.0000	0.445	0.286	0.604
	-	12	22	6	15	10	13	9	15	0.0015**	0.0603	0.0119*	0.224**	0.226**	0.222**
	+-	32	37	17	19	16	15	14	20	0.0005***	0.0150*	0.0325*	0.263**	0.212**	0.313
8	+	17	14	8	3	3	0	0	5	1.0000	0.4311	1.0000	0.601	0.368	0.833
	-	9	12	6	18	4	17	8	20	0.0222*	0.0603	0.3052	0.281**	0.260**	0.302
	+-	26	26	14	21	7	17	8	25	0.1355	0.0325*	0.5206	0.352	0.245**	0.458
9	+	5	6	12	5	13	2	0	0	1.0000	0.1250	1.0000	0.602	0.406	0.798
	-	8	6	8	6	7	16	17	36	0.0018**	0.0603	0.0325*	0.274**	0.365	0.182**
	+-	13	12	20	11	20	18	17	36	0.0036**	0.0854	0.0150*	0.308**	0.376	0.240**
L	+	5	6	7	6	4	0	3	3	1.0000	0.1250	1.0000	0.623	0.423	0.823
	-	8	6	11	6	8	21	7	37	0.0018**	0.0603	0.0325*	0.279**	0.343	0.214**
	+-	13	12	18	12	12	21	10	40	0.0078**	0.0603	0.1250	0.347	0.374	0.320

Table A2

Autocorrelation of daily *individual* stock returns: open-to-close returns (Null Hypothesis IV); Supplement to Table 7. This Table supplements Table 7, whose Panel A reported the Pearson autocorrelation test, by reporting the Andrews test (Panel B) and Kendall τ-test (Panel C). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant autocorrelation at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1%, and 5% levels.

Portfolio		Autocorrelation of daily *individual* stock returns: open-to-close returns								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel B: Andrews' modified Pearson correlation test															
Smallest	+	5	10	26	14	16	9	4	7	0.0466^{*}	0.1250	0.3052	0.305^{**}	0.256^{**}	0.354
	-	2	3	3	6	6	10	11	32	1.0000	1.0000	0.0603	0.507	0.771	0.243^{**}
	+-	7	13	29	20	22	19	15	39	0.0132^{*}	0.5206	0.0247^{*}	0.309^{**}	0.380	0.238^{**}
2	+	20	18	38	17	10	6	5	1	0.0703	0.0009^{***}	1.0000	0.330^{**}	0.119^{**}	0.542
	-	3	2	1	4	12	18	11	24	1.0000	1.0000	0.0053^{**}	0.517	0.865	0.170^{**}
	+-	23	20	39	21	22	24	16	25	0.0002^{***}	0.0078^{**}	0.0191^{*}	0.223^{**}	0.208^{**}	0.237^{**}
3	+	21	19	29	16	3	0	4	2	1.0000	0.0012^{**}	1.0000	0.494	0.123^{**}	0.865
	-	5	2	2	1	26	15	7	21	1.0000	1.0000	0.0325^{*}	0.530	0.875	0.185^{**}
	+-	26	21	31	17	29	15	11	23	0.0036^{**}	0.0150^{*}	0.0854	0.258^{**}	0.221^{**}	0.294
4	+	28	19	30	13	4	1	6	4	0.2701	0.0027^{**}	1.0000	0.395	0.124^{**}	0.667
	-	2	3	3	8	19	26	13	24	1.0000	1.0000	0.0027^{**}	0.438	0.745	0.131^{**}
	+-	30	22	33	21	23	27	19	28	0.0000^{***}	0.0064^{**}	0.0096^{**}	0.203^{**}	0.196^{**}	0.211^{**}
5	+	27	24	17	6	2	5	6	5	0.0703	0.0481^{*}	1.0000	0.397	0.190	0.604^{**}
	-	4	4	5	6	14	20	3	12	0.2701	0.3052	0.1334	0.439	0.542	0.336
	+-	31	28	22	12	16	25	9	17	0.0181^{*}	0.0603	0.1905	0.293^{**}	0.246^{**}	0.341
6	+	25	14	10	5	5	5	3	4	0.2701	0.1250	0.9645	0.436	0.257^{**}	0.615
	-	0	2	3	9	8	6	2	6	1.0000	1.0000	0.9766	0.657	0.778	0.536
	+-	25	16	13	14	13	11	5	10	0.0703	0.0438^{*}	1.0000	0.449	0.314	0.585
7	+	28	17	14	6	4	5	2	2	1.0000	0.0603	1.0000	0.495	0.208^{**}	0.781
	-	4	10	3	3	6	2	5	14	1.0000	0.9645	1.0000	0.580	0.635	0.524
	+-	32	27	17	9	10	7	7	16	0.1355	0.1905	0.5206	0.429	0.298	0.560
8	+	25	11	3	6	4	3	4	3	0.4651	0.9645	0.9645	0.562	0.394	0.729
	-	1	4	6	5	1	8	3	15	1.0000	1.0000	1.0000	0.607	0.635	0.578
	+-	26	15	9	11	5	11	7	18	0.5692	0.1905	1.0000	0.498	0.384	0.612
9	+	8	10	8	7	8	2	1	0	1.0000	0.0325^{*}	1.0000	0.568	0.308	0.828
	-	2	6	6	3	3	9	9	20	1.0000	1.0000	0.3072	0.523	0.667	0.378
	+-	10	16	14	10	11	11	10	20	0.0078^{**}	0.1250	0.1250	0.416	0.417	0.415
Largest	+	8	5	3	8	1	0	7	0	1.0000	0.9645	1.0000	0.664	0.490	0.839
	-	4	5	17	3	2	8	7	24	1.0000	0.9645	0.6312	0.485	0.526	0.443
	+-	12	10	20	11	3	8	14	24	0.2701	0.1250	1.0000	0.476	0.405	0.548

Table A2
Autocorrelation of daily *individual* stock returns: open-to-close returns (Null Hypothesis IV); Supplement to Table 7 — Continued

Panel C: Kendall τ-test															
Smallest	+	11	14	34	21	22	10	4	0	0.2701	0.0053**	1.0000	0.323**	0.150**	0.497
	-	4	5	2	9	9	15	12	45	0.2701	1.0000	0.0119*	0.389	0.601	0.177**
	+-	15	19	36	30	31	25	16	45	0.0003***	0.0247*	0.0191*	0.211**	0.226**	0.196**
2	+	24	23	43	28	12	4	3	2	1.0000	0.0003***	1.0000	0.378	0.090***	0.667
	-	7	4	0	2	15	21	17	34	1.0000	1.0000	0.0015**	0.436	0.746	0.127**
	+-	31	27	43	30	27	25	20	36	0.0000***	0.0024**	0.0078**	0.175***	0.157**	0.194**
3	+	25	26	41	28	6	1	1	1	1.0000	0.0002***	1.0000	0.470	0.087***	0.854
	-	2	2	1	1	24	21	10	28	1.0000	1.0000	0.0078**	0.570	1.000	0.141**
	+-	27	28	42	29	30	22	11	29	0.0004***	0.0024**	0.0854	0.210**	0.164**	0.255**
4	+	31	31	41	17	3	1	5	1	1.0000	0.0009***	1.0000	0.463	0.092***	0.833
	-	1	4	1	9	26	30	15	33	1.0000	1.0000	0.0015**	0.416	0.726	0.105**
	+-	32	35	42	26	29	31	20	34	0.0000***	0.0027**	0.0078**	0.168***	0.153**	0.183**
5	+	34	28	25	16	6	5	7	8	0.0078**	0.0012**	0.1250	0.251**	0.105**	0.397
	-	4	4	6	9	22	26	5	16	0.0466*	0.3052	0.0575	0.351	0.486	0.217**
	+-	38	32	31	25	28	31	12	24	0.0002***	0.0032**	0.0603	0.202**	0.162**	0.241**
6	+	29	19	10	5	5	5	2	2	1.0000	0.1250	1.0000	0.496	0.242**	0.750
	-	0	2	5	7	12	10	2	7	1.0000	1.0000	0.6312	0.584	0.714	0.454
	+-	29	21	15	12	17	15	4	9	0.1343	0.0603	1.0000	0.418	0.290	0.546
7	+	27	24	12	9	6	5	5	3	0.0703	0.0119*	0.9645	0.367	0.171**	0.563
	-	5	6	2	5	7	7	4	13	0.2701	1.0000	0.3052	0.494	0.604	0.383
	+-	32	30	14	14	13	12	9	16	0.0181*	0.0325*	0.1905	0.338	0.259**	0.417
8	+	27	12	6	9	7	2	3	3	1.0000	0.0603	1.0000	0.502	0.249**	0.756
	-	2	6	6	6	3	7	4	18	1.0000	0.9766	0.9645	0.526	0.563	0.489
	+-	29	18	12	15	10	9	7	21	0.1343	0.0603	0.5206	0.401	0.300	0.502
9	+	8	9	6	5	10	2	3	2	1.0000	0.1250	1.0000	0.574	0.377	0.771
	-	2	5	8	3	8	9	7	22	1.0000	1.0000	0.0325*	0.463	0.661	0.265
	+-	10	14	14	8	18	11	10	24	0.0466*	0.3052	0.1250	0.410	0.460	0.360
Largest	+	11	4	4	3	3	0	5	0	1.0000	0.9645	1.0000	0.705	0.578	0.833
	-	5	7	22	4	6	14	7	33	0.0466*	0.3052	0.0603	0.328**	0.399	0.257**
	+-	16	11	26	7	9	14	12	33	0.1343	0.5206	0.1905	0.394	0.418	0.370

Table A3

ETFs (Null Hypothesis VII); Supplement to Table 12. This Table supplements Table 12, whose Panel A reported the Pearson autocorrelation test, by reporting the Andrews test (Panel B) and Kendall τ-test (Panel C). We report the number of firms exhibiting positive (+), negative (-), and two-sided (+-) significant correlation with the prior SPDR return at the 2.5% one-sided (5% two-sided) levels. We report a *p*-value, p_3, derived from the first and second order statistics (minimum and second lowest) of the observations for the eight two-year time-horizon subperiods in 93-08, as well as for the four two-year time-horizon subperiods in 93-00 and 01-08. We also report p_4, the average of the *p*-values over the eight or four two-year time-horizon subperiods; p_4 is not itself a *p*-value, and significance levels are determined by Monte Carlo simulation. ***, **, and * denote significance at the 0.1%, 1% and 5% levels.

Portfolio		Correlation of daily *individual* stock returns and SPDRs								Binomial *p*-value			Average *p*-value		
		93-94	95-96	97-98	99-00	01-02	03-04	05-06	07-08	93-08	93-00	01-08	93-08	93-00	01-08
										p_3	p_3	p_3	p_4	p_4	p_4
Panel B: Andrews' modified Pearson correlation test															
Smallest	+	16	18	31	13	16	8	17	2	0.0034**	0.0027**	0.4311	0.273**	0.142**	0.404
	-	0	0	1	1	4	9	7	23	1.0000	1.0000	0.3052	0.671	1.000	0.342
	+-	16	18	32	14	20	17	24	25	0.0005***	0.0325*	0.0150*	0.257**	0.276	0.238**
2	+	22	24	32	12	5	4	2	3	1.0000	0.0038**	1.0000	0.433	0.126**	0.740
	-	0	1	0	1	12	7	7	20	1.0000	1.0000	0.0325*	0.631	1.000	0.262
	+-	22	25	32	13	17	11	9	23	0.0181*	0.0438*	0.1905	0.311**	0.242**	0.380
3	+	29	36	26	21	6	4	11	1	0.2701	0.0004***	1.0000	0.330**	0.093***	0.567
	-	2	0	2	2	19	9	6	27	1.0000	1.0000	0.0603	0.615	1.000	0.230**
	+-	31	36	28	23	25	13	17	28	0.0010***	0.0045**	0.0438*	0.219**	0.174**	0.264
4	+	31	31	27	17	3	6	7	3	0.4651	0.0009***	0.9645	0.355	0.100**	0.610
	-	0	0	1	7	11	11	11	27	1.0000	1.0000	0.0053**	0.516	0.839	0.194**
	+-	31	31	28	24	14	17	18	30	0.0005***	0.0038**	0.0325*	0.226**	0.177**	0.274
5	+	41	29	22	19	8	8	18	4	0.0034**	0.0006***	0.3052	0.223**	0.098**	0.347
	-	0	0	5	4	9	7	2	21	1.0000	1.0000	0.6312	0.610	0.781	0.438
	+-	41	29	27	23	17	15	20	25	0.0003***	0.0045**	0.0247*	0.222**	0.174**	0.269
6	+	39	34	26	15	6	11	15	2	0.0222*	0.0015**	0.9766	0.276**	0.100**	0.453
	-	0	1	2	12	5	4	1	9	1.0000	1.0000	1.0000	0.701	0.802	0.601
	+-	39	35	28	27	11	15	16	11	0.0036**	0.0024**	0.0854	0.274**	0.159**	0.389
7	+	37	38	33	12	15	5	15	5	0.0078**	0.0038**	0.1250	0.219**	0.104**	0.333
	-	0	0	3	12	0	1	0	12	1.0000	1.0000	1.0000	0.781	0.760	0.802
	+-	37	38	36	24	15	6	15	17	0.0052**	0.0038**	0.5185	0.301**	0.153**	0.449
8	+	29	41	19	10	15	4	7	4	0.0466*	0.0078**	0.3052	0.288**	0.132**	0.443
	-	0	0	6	14	0	5	2	23	1.0000	1.0000	1.0000	0.650	0.649	0.652
	+-	29	41	25	24	15	9	9	27	0.0181*	0.0038**	0.1905	0.292**	0.176**	0.407
9	+	23	36	13	17	10	1	4	4	1.0000	0.0027**	1.0000	0.377	0.129**	0.625
	-	2	0	10	21	3	12	8	27	1.0000	1.0000	0.4311	0.477	0.592	0.362
	+-	25	36	23	38	13	13	12	31	0.0018**	0.0045**	0.0603	0.254**	0.172**	0.337
Largest	+	9	35	10	12	1	0	0	5	1.0000	0.0119*	1.0000	0.538	0.202**	0.875
	-	3	0	8	17	2	23	7	35	1.0000	1.0000	0.6312	0.479	0.573	0.384
	+-	12	35	18	29	3	23	7	40	0.5692	0.0603	1.0000	0.383	0.252**	0.514

Table A3
ETFs (Null Hypothesis VII); Supplement to Table 12 — Continued

							Panel C: Kendall τ-test								
Smallest	+	16	16	36	9	16	6	13	1	0.0222*	0.0119*	0.9766	0.303**	0.165**	0.441
	-	0	0	0	0	8	11	6	53	1.0000	1.0000	0.0603	0.625	1.000	0.251**
	+-	16	16	36	9	24	17	19	54	0.0034**	0.1905	0.0150*	0.272**	0.330	0.215**
2	+	25	19	47	13	4	2	3	1	1.0000	0.0027**	1.0000	0.492	0.119**	0.865
	-	0	0	0	1	18	16	6	43	1.0000	1.0000	0.0575	0.596	1.000	0.192**
	+-	25	19	47	14	22	18	9	44	0.0082**	0.0325*	0.1905	0.263**	0.232**	0.294
3	+	29	31	38	20	5	5	3	3	0.4651	0.0005***	0.9645	0.378	0.089***	0.667
	-	1	0	1	2	23	19	6	42	1.0000	1.0000	0.0347*	0.590	1.000	0.179**
	+-	30	31	39	22	28	24	9	45	0.0004***	0.0053**	0.1334	0.217**	0.171**	0.263
4	+	31	24	46	14	3	1	9	1	1.0000	0.0020**	1.0000	0.441	0.104**	0.778
	-	0	0	1	6	20	19	12	39	1.0000	1.0000	0.0038**	0.493	0.854	0.132**
	+-	31	24	47	20	23	20	21	40	0.0000***	0.0078**	0.0078**	0.195***	0.182**	0.208**
5	+	37	30	52	20	8	5	10	4	0.0466*	0.0005***	0.3052	0.251**	0.081***	0.422
	-	0	0	3	6	15	13	5	28	1.0000	1.0000	0.1056	0.525	0.813	0.237**
	+-	37	30	55	26	23	18	15	32	0.0003***	0.0027**	0.0247*	0.196***	0.146**	0.246**
6	+	44	30	44	10	11	7	12	2	0.0082**	0.0078**	0.6312	0.280**	0.112**	0.448
	-	0	0	3	10	7	11	2	12	1.0000	1.0000	0.6312	0.610	0.771	0.448
	+-	44	30	47	20	18	18	14	14	0.0005***	0.0078**	0.0325*	0.238**	0.159**	0.317
7	+	35	39	52	17	21	3	8	5	0.0703	0.0009***	0.9645	0.262**	0.083***	0.441
	-	0	0	3	11	4	3	2	21	1.0000	1.0000	1.0000	0.705	0.765	0.644
	+-	35	39	55	28	25	6	10	26	0.0703	0.0020**	0.9645	0.283**	0.135**	0.431
8	+	32	34	47	7	22	6	5	2	0.0703	0.0074**	1.0000	0.324**	0.140**	0.508
	-	1	2	8	17	0	11	4	25	1.0000	1.0000	1.0000	0.551	0.615	0.488
	+-	33	36	55	24	22	17	9	27	0.0023**	0.0038**	0.1905	0.231**	0.147**	0.316
9	+	25	32	28	17	18	1	3	1	1.0000	0.0009***	1.0000	0.423	0.104**	0.743
	-	2	0	9	25	8	26	10	43	1.0000	1.0000	0.0191*	0.387	0.594	0.179**
	+-	27	32	37	42	26	27	13	44	0.0001***	0.0024**	0.0438*	0.184***	0.149**	0.219**
Largest	+	14	23	25	13	9	0	0	1	1.0000	0.0027**	1.0000	0.482	0.145**	0.819
	-	3	0	3	16	7	37	13	56	1.0000	1.0000	0.0325*	0.436	0.706	0.165**
	+-	17	23	28	29	16	37	13	57	0.0010***	0.0150*	0.0438*	0.223**	0.216**	0.230**