Examination of long-run performance of momentum portfolios: Implications for the sources and profitability of momentum

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(ABSTRACT)

This dissertation investigates the long-term performance of momentum portfolios. Its results show striking asymmetries for winners and losers and imply potentially different causes for the winner and loser components of momentum.

After separately examining winners and losers relative to their respective benchmark portfolios with no momentum, we find winner momentum is smaller in magnitude, persists only for six months, and its higher return fully reverses. This is consistent with the notion that winner momentum is an overreaction to positive news and potentially destabilizing. Loser momentum is larger in magnitude, lasts for about one year, and its lower return does not reverse in the long run. This is consistent with the notion that loser momentum is an underreaction to negative news and suggests investors hold on to losers for too long.

The lack of reversal for losers departs from prior studies whose findings are driven by the use of monthly rebalanced portfolio. Rebalancing cumulates an upward bias caused by noise-induced price volatility, which disproportionately affects losers more. This greater upward bias in losers creates an illusion that the winner minus loser return reverses. More appropriate approaches such as the buy-and-hold portfolio documents significantly less reversal.

Existing theories that potentially conform to the overreaction of winners and underreaction of losers include overconfidence (Daniel, Hirshleifer, and Subrahmanyam, 1998), representativeness and conservatism (Barberis, Shleifer, and Vishny, 1998), interaction between agents holding asymmetric information (Hong and Stein, 1999), and investors' asymmetric response to fund performance (Vayanos and Woolley, 2013).

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(GENERAL AUDIENCE ABSTRACT)

The method employed to study a phenomenon can have an immense impact on our understanding. In the specific context of momentum - a strategy of buying stocks with good past performance and selling stocks with bad past performance, we show that the methodology choices as simple as how you form a portfolio and what you benchmark the portfolio against can produce significantly different results than previously documented.

The documented pattern that momentum reverses over the long run, is confounded by the use of rebalanced portfolio and benchmarking winner and loser stocks against each other. Rebalancing embeds an upward bias into the return, with the bias increasing in the amount of noise in the price. Losers, having lower prices and smaller market values, suffer more from the upward bias. Thus, the reversal of the winner over loser return is more due to the inflated loser return from the bias than an underlying economic phenomenon. We confirm this by using a host of other portfolio formation methods that are known to mitigate the bias. With each of the other method, the loser return and the reversal are significantly reduced.

We also suggest comparing winners and losers to a neutral benchmark with no momentum, rather than with each other to study the long-term pattern of momentum. This exercise turns out to be fruitful in that we find asymmetric behavior for winners and losers. Winner momentum fully reverses while loser momentum persists. The significance of the new results is that they affect our understanding of what drives momentum in the first place. The reversal of winners implies that winner momentum is an overreaction to positive news and potentially destabilizing. The persistence of losers indicates that loser momentum is an underreaction to negative news and implies investors hold on to losers for too long.

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Chapter 1

Introduction

One of the stylized facts about momentum – the strategy of buying stocks with high past returns and selling stocks with low past returns – is that it yields a positive return over the intermediate horizon, but a negative return over the long horizon. Tracking momentum strategy formed on past 3-12 month returns, Jegadeesh and Titman (1993) show that it earns a significant 10% return over the first year, more than half of which reverses by the end of the third year. Subsequent studies confirm the negative return of momentum over the long horizon, with the reversal erasing 70% to over 100% of the positive return of the first year.[1] Reversal can obtain under overreaction when price eventually corrects. Accordingly, the literature has favored overreaction as the explanation for momentum and characterized its possible sources.[2]

Given the implication of reversal on the causes of momentum, we begin our study by re-examining this evidence. Specifically, we track the return of momentum portfolios for five years following their formation. Our emphasis is on the long run – between the second

[1]For instance, the magnitude of reversal has been documented at 70% (Nagel, 2001), 100% (Jegadeesh and Titman, 2001) to over 100% (Ali, Daniel, and Hirshleifer, 2017). More papers that provide evidence on momentum reversal include Moskowitz and Grinblatt (1999), Lewellen (2002), Griffin, Ji, and Martin (2003), George and Hwang (2004), Mclean (2010) and Jegadeesh and Titman (2011).

[2]The sources of overreaction have been traced to positive feedback trading (De Long, Shleifer, Summers, and Waldmann, 1990), representative heuristic (Barberis, Shleifer, and Vishny, 1998), over-confidence (Daniel, Hirshleifer, and Subrahmanyam, 1998), individual trading (Cohen, Gompers, and Vuolteenaho, 2002), fund flows (Vayanos and Woolley, 2013), and asymmetric information (Albuquerque and Miao, 2014, Andrei and Cujean, 2017, Hong and Stein, 1999).

through the fifth year – where reversal is expected to occur.[3] The prior evidence of momentum reversal is inconclusive, in our assessment, due to methodological problems of (i) measurement for portfolio return, (ii) appropriate benchmarks for extreme momentum portfolios, and (iii) survivorship. After using buy-and-hold portfolio return as opposed to the prevailing rebalanced return, benchmarking winners and losers against their respective matched control firms with no momentum in returns and controlling for survivorship bias, we document the following new results.

First, we show that previous studies overestimate the extent of the winner-loser reversal by the use of rebalanced portfolio return. An alternative buy-and-hold return largely diminishes the magnitude of reversal. Over the entire five years of the post-formation period in our sample, losers outperform winners by about 20% when we rebalance the portfolio every month. But they continue to underperform winners by about 5% when we buy-and-hold the portfolio. Further, we attribute this difference to the upward bias in rebalanced return related to noise-induced price volatility. Since this price volatility is higher for losers because of their lower prices and smaller market values as compared to winners, the upward bias introduced in rebalanced returns for the loser portfolio overwhelms the upward bias in the winner portfolio. This leads to an incorrect observation that the winner-loser momentum profit reverses. Controlling for the noise-induced price volatility, we find reversal is much attenuated. Even with the rebalanced return, losers perform about the same as winners, yielding a 0% return difference over the entire five years. This contrasts with 20% outperformance for losers using rebalanced return but without a control for noise-induced volatility.

[3]We are aware that there is a separate long-term contrarian literature. Even though we both investigate long-term returns, long-term contrarian strategy (starting with De Bondt and Thaler (1985, 1987)) selects stocks based on their long-term past returns, generally 3 to 5 years. Whereas we examine momentum, a strategy based on stocks' intermediate-term returns, conventionally 3 to 12 months. Analyzing the data, stocks in the long-term contrarian and momentum portfolios are very much different, suggesting these two are separate phenomena. As the focus of this paper, the term reversal refers to the reversal of the return to momentum portfolios, not to long-term contrarian portfolios.

Second, we find asymmetry in how losers and winners behave long-term relative to their respective benchmarks. Loser momentum persists for about one year with approximately 10% lower returns as compared to a matched benchmark portfolio. Moreover, these lower returns do not reverse with the losers earning the same as the benchmark over the next four years. In contrast, winner momentum persists only for six months and is smaller in magnitude, about 2% higher returns for the first six months as compared to a matched benchmark portfolio. Additionally, these higher returns reverse with winners underperforming the benchmark by about 15% over the next four years. The 15% lower return completely wipes out winners' higher return during the first six months and a part of their formation period return.

Last, we highlight an overlooked feature of momentum portfolios in examining their long-run performance – survivorship bias. In general, the extreme portfolios of winners and losers exhibit significantly lower survival rates relative to other portfolios. The five-year mortality rate for winners and losers are as high as 30% and 50%. More importantly, there is a stark contrast in terms of the reasons for the observed exits. The majority of losers drop out for bankruptcies while the majority of winners drop out for mergers. This leads to a significant difference between the long-term returns of surviving and non-surviving sample within each momentum portfolio, especially within the losers. Over the five years, surviving losers earn twice as much as non-surviving losers. Including only surviving stocks would overstate the long-run performance of losers, and might bias the results in favor of a reversal. We control the bias by using the entire sample – surviving and non-surviving – and reinvesting the wealth of non-surviving stocks back into the portfolio.

Details of the comparison between rebalanced and buy-and-hold return date back to Blume and Stambaugh (1983) and Roll (1983), and are later echoed in Conrad and Kaul (1993), Canina, Michaely, Thaler, and Womack (1998), Boynton and Oppenheimer (2006), Liu and

Strong (2006) and Asparouhova, Bessembinder, and Kalcheva (2013).[4] They show that individual stock return contains an upward bias when the observed price is subject to noise, and the bias is increasing with the volatility of the noise. Noise includes any temporary deviations of observed price from the underlying value, which can take the form of price impacts from order imbalances, microstructure frictions such as bid-ask spreads, price discreteness and non-synchronous trading, and behavioral factors. At the portfolio level, rebalancing, where returns are averaged and then compounded over the holding period, effectively cumulates the positive bias in individual stock returns. Buy-and-hold, where individual returns over the holding period are calculated and then averaged, largely reduces the bias. This is evident in our results as rebalancing consistently produces a higher return than buy-and-hold for all the momentum portfolios. The difference is minimal for winners, with their five-year cumulative rebalanced return exceeding buy-and-hold return by about 5%. But the difference for losers climbs to almost 30%. This non-trivial difference suggests losers are more prone to high noise-induced price volatility. This is not surprising given that the average loser has a price and market value of $10.56 and $162.16 million, respectively, and the average winner has a price and market value of $28.00 and $563.99 million, respectively – nearly three times as larger as the average loser. The greater upward bias in losers' return creates a false impression of reversal for the winner minus loser momentum profit.

To further test that price volatility drives the difference between rebalanced and buy-and-hold return, we use a matched sample design controlling for price and market value, which act as our controls for noise-induced price volatility. With a +/- 30% screen on price and market value, we end up with about half of the losers finding a match from the winners. Comparing the matched and the unmatched samples of losers (or winners), buy-and-hold portfolios show no recognizable difference in returns – as the method largely corrects for the bias from price volatility, while rebalanced portfolios exhibit significantly higher return for

[4]These cited papers illustrate the comparison in contexts other than long-term momentum returns.

the sample with higher volatility – as the method exaggerates the bias. The unmatched losers have higher price volatility relative to the matched losers, and earn a rebalanced return that is 30% higher over the five-year post-formation period, though both have similar formation period returns and similar post-formation returns under the buy-and-hold method. Similarly, the unmatched winners have lower price volatility relative to the matched winners, and show a rebalanced return that is 5% lower. The volatility-related upward bias in rebalanced return and the resulting incorrect inference of reversal is further confirmed by comparing matched winners and losers. Even with rebalanced returns, the matched losers and winners have similar returns over the entire five years, as compared to 20% higher returns for losers without the volatility matching. To establish the plausibility of noise to generate such large bias in rebalanced return, we also form tercile sub-portfolios within each momentum portfolio based on other proxies of noise – price, idiosyncratic volatility and Amihud (2002) illiquidity measure. Consistent with our matching results, the tercile sub-portfolios display similar buy-and-hold return, but reveal significantly higher rebalanced return with the tercile that has a higher noise level.

Beyond price volatility differential, winners and losers possibly face different return dynamics, which vexes the question of what their neutral benchmarks should be to detect reversal or lack thereof. Earlier studies base their conclusions on the strategy that enters a long position in the portfolio of winners and a short position of losers, effectively using one as the benchmark for the other. This may be problematic for two reasons. First, as argued earlier the asymmetric nature of their noise-induced price volatilities will differentially impact the upward bias in rebalanced returns. Second and more importantly, the fact that winners and losers are experiencing momentum but in different directions likely subjects their long-term returns to different return dynamics.[5] A simple comparison of winners against losers does

[5]The literature – empirical and theoretical – on distressed stocks show that their pricing is different from their counterpart, e.g., Campbell, Hilscher, and Szilagyi (2011).

not allow us to make any meaningful inferences on the possibly different long-term return dynamics of each. As an example, a 'net' reversal of winners over losers could be the result of winner reversing more or persisting less. We reason that the better benchmarks for both the winner and the loser portfolios would be a characteristic-based matching portfolio with no momentum during the formation period – and if using rebalanced returns, with similar noise-induced price volatility. The primary characteristics we use are price and market value, controlling for both noise-induced price volatility and size-related expected return, and the stocks with no momentum are from the median portfolios 5 and 6.

Compared to their matched benchmark portfolio, losers underperform by about 10% during the first year but show no significant difference in returns for the following four years. The lack of reversal in losers is inconsistent with overreaction but consistent with an alternative hypothesis such as underreaction wherein we expect no distinguishable pattern in returns after prices fully incorporate information.[6] On the contrary, winners outperform by about 2% relative to their matched benchmark during the first year but experience severe underperformance thereafter. Their entire five-year cumulative return is 15% lower than that of their benchmark. The reversal in winners is particularly strong and consistent with overreaction.

Our methodological contribution lies in highlighting the importance of using buy-and-hold as opposed to rebalanced return to minimize the upward bias related to noise-induced price volatility, and of having robust control for survivorship bias in the context of long-term momentum return.[7] Few studies have used buy-and-hold portfolios to examine momentum

[6]Papers support the underreaction hypothesis for momentum include Lesmond, Schill, and Zhou (2004), Grinblatt and Han (2005), and Da, Gurun, and Warachka (2014).

[7]Outside the context of momentum, the buy-and-hold approach is more wildly adopted in the long-horizon event studies following Ikenberry, Lakonishok, and Vermaelen (1995), Barber and Lyon (1997), Lyon, Barber, and Tsai (1999), and Mitchell and Stafford (2000). Though suffering less from the noise-induced bias compared to rebalancing, buy-and-hold is not short of its vice, mainly the skewness and cross-correlation in its return that renders the traditional test statistics unreliable. We apply a correlation and heteroscedasticity-consistent test as in Jegadeesh and Karceski (2009).

return, even fewer on their impact on long-term return.[8] While most papers focus on the upward bias based on rebalanced daily returns, we emphasize that the rebalancing bias could also affect inference using monthly returns given the time period is long enough and there is differential price volatility across the long and short portfolios.[9] To our knowledge, the matching procedure introduced to illustrate the rebalancing bias in the winners and losers and to form their respective benchmarks is novel in the momentum literature. The issue of survival of momentum portfolios has not been received much explicit attention. Few papers[10] briefly mention the high mortality rate of winners and losers within the first six months but do not examine its implication. We make sure to include all sample stocks and reinvest the wealth of non-surviving stocks to account for survivorship bias.[11]

In addition, our results provide a better and richer understanding of momentum's long-term patterns and causes. We propose to examine winners and losers separately with their appropriate benchmarks for they could be driven by different sources while most efforts to date have been put into finding a single cause for both. It is worth reflecting on how existing theories support the long-term asymmetric pattern of winners and losers we document. Studies only explain over- or under-reaction would fail to reconcile both sides of momentum. For instance, the slow adjusting of loser momentum is inconsistent with the positive

[8] An exception is Liu and Strong (2006), which refutes the relation between momentum and business cycle in Chordia and Shivakumar (2002) using buy-and-hold portfolio returns instead of rebalancing returns.

[9] The empirical part of Blume and Stambaugh (1983) and Roll (1983) demonstrate the bias with an application to the size premium using daily return by compounding over one year; Conrad and Kaul (1993) examine the bias in long-term contrarian strategy; Canina, Michaely, Thaler, and Womack (1998) show the bias at the aggregate index level using daily return and compounding it over one month; the momentum investigation of Boynton and Oppenheimer (2006) and Liu and Strong (2006) do not focus on the long term – both only look up to six months after the momentum formation; the empirical part of Asparouhova, Bessembinder, and Kalcheva (2013) considers portfolios associated with five firm characteristics – size, book-to-market, volume, price and Amihud (2002) illiquidity measure using monthly returns.

[10] Grundy and Martin (2001) and Avramov, Chordia, Jostova, and Philipov (2007).

[11] This approach hinges on the accuracy of the delisting returns. To the extent that the delisting return of non-surviving stocks does not capture the entire effect of delisting and surviving and non-surviving sample differ, we caution the potential bias of a changing sample over time. Especially information about acquisition or bankruptcy is a likely cause of winners' superior or losers' subpar performance during the formation period. This concern has been raised in other contexts (Brown, Goetzmann, and Ross, 1995, Kothari, Sabino, and Zach, 2005).

feedback trading behavior of De Long, Shleifer, Summers, and Waldmann (1990) and the reversal of winner momentum is inconsistent with the disposition effect of Grinblatt and Han (2005) or investor attention of Da, Gurun, and Warachka (2014). Studies that address both over- and under-reaction are more likely to conform to but not without challenges.[12] The overconfidence of Daniel, Hirshleifer, and Subrahmanyam (1998) posits investors over-react to private information but slowly adapt to public information. For it to be consistent with our finding, we could test if price of winners incorporates more private information and of losers more public information. The two-regime framework in Barberis, Shleifer, and Vishny (1998) assumes that assets are either in a trending regime or mean-reverting regime. But further examination on how losers consistently stay in the trending regime but winners switch to the mean-reverting regime is needed. Similarly, the interaction of "newswatchers" and "momentum traders" in Hong and Stein (1999) means we need to answer if losers are dominated by "newswatchers" who gradually observe information and winners by "momentum traders" who accelerate the process but overshoot. The most promising is the fund flow model of Vayanos and Woolley (2013) that relies on investors quickly reacting to winners' good performance to generate over-reaction and slowly reacting to losers' bad performance to cause under-reaction. This asymmetric response is consistent with the wildly documented fund flow to performance relationship.[13]

This paper broadly speaks to the literature that relates long-run momentum return to other variables. Lee and Swaminathan (2000) link the persistence of momentum to trading volume. They show the winner-loser momentum reversal is the most pronounced between high turnover winners and low turnover losers, and the least pronounced between low turnover winners and high turnover losers. Nagel (2001) shows that reversal is a book-to-market ef-

[12]The literature has also attempted risk-based explanation (Ahn, Conrad, and Dittmar, 2003, Avramov and Chordia, 2006, Chordia and Shivakumar, 2002, Conrad and Kaul, 1998, Holden and Subrahmanyam, 2002). But as Jegadeesh and Titman (2011) state in their review paper "In our opinion, the magnitude and persistence of these returns are too strong to be explained by risk".

[13]E.g., see Sirri and Tufano (1998).

fect. Reversal disappears after returns are adjusted for returns of a reference portfolio based on size and book-to-market. Cohen, Gompers, and Vuolteenaho (2002) find that momentum reversal is more severe for individual trading instead of institutional trading. Cooper, Gutierrez, and Hameed (2004) examine the long-run momentum returns conditioning on market states. They find momentum reverses more following down-market than following up-market. Antoniou, Doukas, and Subrahmanyam (2010) relate momentum to investment sentiment and show momentum formed during periods of optimism experience stronger reversal over the long-run. Da, Gurun, and Warachka (2014) find that momentum relates to their information discreetness variable. Continuous information identified by information discreteness proxy induces a stronger, more extended, non-reversal momentum return than discrete information. Ali, Daniel, and Hirshleifer (2017) find the long-horizon performance of momentum portfolios is negatively related to realized momentum performance in the past two years leading up to the formation date. Our paper suggests that momentum reversal depends upon the bias induced by price volatility when using rebalanced returns. To the extent those variables suggested by other papers are correlated with price volatility, they would have no unique role for predicting momentum reversal beyond price volatility.

We organize the remainder of the chapters as follows. Chapter 2 describes the data sources, the effect of different methodological approaches on the portfolio return estimates and our matching procedure. Chapter 3 presents the empirical results. Chapter 4 discusses the survivorship bias. Chapter 5 contains robustness tests with a focus to confirm the magnitude of the rebalancing bias and Chapter 6 concludes.

Chapter 2

Data and Methodology

We obtain monthly stock returns from the Center for Research in Security Prices (CRSP). Our sample includes US common stocks (CRSP share codes of 10 or 11). Whenever a stock disappears from the sample, we make sure to include its delisting return. Whenever a stock is missing its delisting return, we use a replacement value of -50% if delisting is performance-related and of 0% if delisting is non-performance-related.[14] We construct book values of equity using COMPUSTAT. Following Davis, Fama, and French (2000), book values are defined as the book value of stockholders' equity, plus balance sheet deferred taxes and investment tax credit (if available), minus the book value of preferred stock. The time period spans from June 1951 – December 2016.[15]

2.1 Portfolio Formation

We investigate returns on momentum portfolios sorted by past returns. Following the momentum literature, at the end of each month (month -1), we rank stocks on the basis of their cumulative returns over the previous 6 months, denoted as $R_{[-6,-1]}$,[16] and place them into 10

[14] For replacement values for missing delisting returns and the identification of missing delisting returns in the CRSP monthly file, see Shumway (1997), Shumway and Warther (1999) and Beaver, Mcnichols, and Price (2007).

[15] The choice of starting the sample in 1951 reflects i) the availability of the COMPUSTAT data; and ii) the evidence that momentum itself is non-existent pre-1950 (See Conrad and Kaul (1998) and Chordia and Shivakumar (2002)).

[16] On the other hand, forming portfolios based on the past 11-month cumulative returns is more commonly observed in the momentum factor literature (starting with Carhart (1997)).

decile portfolios. The bottom decile, Decile 1 holds the worst performing stocks and forms the loser portfolio. The top decile, Decile 10 holds the best performing stocks and forms the winner portfolio. We leave a one-month gap after month -1 before tracking the portfolios' returns over the next five years to lessen the effect from short-term reversals documented in Jegadeesh (1990) and Lehmann (1990).[17] Month -6 to month -1 is commonly referred to as the formation period (or ranking or identification period), month 1 to 12 as the holding period (our intermediate period), and month 13 to month 60 as the post-holding period (our long-term period).[18] Each portfolio is equally weighted at the initial month 0. We then repeat the process by rolling to the next month as a new portfolio formation date. Table 1 presents the average characteristics – price, market value of equity, book-to-market ratio, beta and monthly return standard deviation – for each momentum portfolio at the end of the formation month.

2.2 Bias in Rebalanced vs. Buy-and-Hold Portfolio Returns

Following Blume and Stambaugh (1983), let $P_{i,t}$ denote the true value and $\hat{P}_{i,t}$ denote the observed price of security i at time t. Any divergence of observed price from true price is captured in noise term $\theta_{i,t}$. Examples of noise include price impacts from order imbalances, microstructure frictions such as bid-ask spreads and nonsynchronous trading, and behavioral

[17] In the event of a delisting after the end of the formation period but before the beginning of the holding period (i.e., at month 0), the delisted stock never enters any momentum portfolio because it has all missing returns for the entire holding and postholding periods. Before we hold the portfolio at the end of month 0, we already know which stock has delisted so there is no look-ahead bias in this treatment.

[18] Theoretical models do not offer any guidance regarding the length of the holding vs. postholding periods over which reversals due to overreaction are expected to occur.

factors.[19] The relation between the true and observed price can be modeled as $\hat{P}_{i,t} = [1 + \theta_{i,t}]P_{i,t}$[20]. The true (gross) return for security i for period t, assuming no dividends for simplicity, is $R_{i,t} = \frac{P_{i,t}}{P_{i,t-1}}$. However, the measured return using observed prices is $\hat{R}_{i,t} = \frac{\hat{P}_{i,t}}{\hat{P}_{i,t-1}}$. The relation between their expected values is thus $E(\hat{R}_{i,t}) = E[\frac{(1+\theta_{i,t})}{(1+\theta_{i,t-1})}]E(R_{i,t})$. By Jensen's inequality, $E[\frac{(1+\theta_{i,t})}{(1+\theta_{i,t-1})}] > 1 \Rightarrow E(\hat{R}_{i,t}) > E(R_{i,t})$. Expanding using a Taylor series, we can approximate the upward bias in individual security's returns as

$$E(\hat{R}_{i,t}) \approx E(R_{i,t})[1 + \sigma^2(\theta_{i,t-1})] \tag{2.1}$$[21]

Equation (2.1) shows that the upward bias is an increasing function of the variance of the noise in price. The main point is that even if the noise is zero on average and does not affect the expectation of price, its volatility will bias the expectation of observed return because return is a non-linear function of price. The direction of the bias is positive due to Jensen's inequality and the magnitude of the bias is increasing with the volatility of the noise.[22] If loser stocks suffer more from noise-induced price volatility compared to winner stocks, they would have a greater upward bias in their observed returns.

Many empirical studies, including those of momentum, compute a portfolio return. Now consider a sample of N securities whose returns are aggregated to a portfolio level. The

[19] Earlier studies formulate the bias only in terms of microstructure measurement errors such as bid-ask spread. But the intuition, which we discuss later, is that *any* noise in the observed stock price will lead to an upward bias in returns.

[20] Blume and Stambaugh (1983) impose the independence assumption on $\theta_{i,t}$. Asparouhova, Bessembinder, and Kalcheva (2013) relax the independence assumption across periods and across securities and show that buy-and-hold method is not necessarily consistent, but is still less biased than rebalanced method.

[21] Asparouhova, Bessembinder, and Kalcheva (2013) generalize the relation in equation (2.1) to allow for autocorrelation in the noise term: $E(\hat{R}_{i,t}) \approx E(R_{i,t})[1 + \sigma^2(\theta_{i,t-1})(1 - \rho)]$ where ρ is the first-order autocorrelation of the noise. As long as $\rho < 1$, the difference between the mean observed return and the true return increases with $\sigma^2(\theta_{i,t-1})$. Note this deviates from the usual assumption of unbiased returns, i.e., the observed expected return $E(\hat{R}_{i,t}) = E(R_{i,t})$ or the expectation of the error term in the return equation is zero.

[22] You may notice there will be no upward bias in log return. However, log return suffers from several drawbacks, one being that the average of the log individual stock returns does not equal to the log of the average individual stocks returns.

rebalancing method first calculates the portfolio return each period (e.g., each month) as an arithmetic average of the returns on individual securities. Then it compounds monthly portfolio returns over time T, i.e., $\hat{R}_{RB,T} = \prod_t (\frac{1}{N}\sum_i \hat{R}_{i,t})$. This would be the actual investment return on a portfolio which begins with equal investments in the N securities and maintains equal investments by rebalancing at the end of each time t. However, with noise, the observed rebalancing return has an expectation of

$$\begin{aligned} E(\hat{R}_{RB,T}) &= [\frac{1}{N}\sum_i E(\hat{R}_{i,t})]^T \approx \{\frac{1}{N}\sum_i E(R_{i,t})[1+\sigma^2(\theta_{i,t-1})]\}^T \\ &\approx E(R_{RB,T}) + T * \frac{1}{N}\sum_i E(R_{i,t})\sigma^2(\theta_{i,t-1}) \end{aligned} \tag{2.2}$$

Not only rebalancing compounds the true portfolio returns, but it also compounds the average of the upward bias in individual security returns. Moreover, the bias increases with the compounding interval.

An alternative method, buy-and-hold, first cumulates individual security return over the entire period T. Then it averages the holding period return of each security, i.e., $\hat{R}_{BH,T} = \frac{1}{N}\sum_i (\prod_t \hat{R}_{i,t}) = \frac{1}{N}\sum_i \hat{R}_{i,T}$. This mimics a strategy that invests an equal amount in each security at initial time 0, then holds the portfolio until time T.[23] This produces a mean return whose expectation is

$$\begin{aligned} E(\hat{R}_{BH,T}) &= E(\frac{1}{N}\sum_i \hat{R}_{i,T}) \approx \frac{1}{N}\sum_i E(R_{i,T})[1+\sigma^2(\theta_{i,0})] \\ &= E(R_{BH,T}) + \frac{1}{N}\sum_i E[R_{i,T}]\sigma^2(\theta_{i,0}) \end{aligned} \tag{2.3}$$

The observed buy-and-hold return equals the true buy-and-hold return plus a constant bias, the bias created by the noise in the price at the beginning of the first period, which is

[23] In other words, there is no active rebalancing in buy-and-hold. However, whenever a security delists, implicit rebalancing is forced to happen as one reallocates the remaining position in the delisting security. A detailed discussion about the treatment after delisting for buy-and-hold portfolio return is in Chapter 4.

invariant with respect to the length of the holding period. This contrasts with cumulated bias in rebalancing from the noise in the price at the beginning of each period.

So far we have conjectured that (i) loser stocks will have a larger upward bias in their observed returns due to greater noise-induced price volatility; and (ii) rebalancing exacerbates the upward bias as the holding period increases given it cumulates the bias for each period over time. Taken together, noise in observed price, not the true return, contributes to the reversal in rebalanced winner-loser portfolio returns over long term.

The analysis in this section assumes that all N securities have observed returns for T periods, i.e., all of them survive the holding period. When in reality, securities drop out of the sample due to various reasons. We defer any detailed treatment of handling survivorship to Chapter 4.

2.3 A Conceptual Argument for Using Buy-and-Hold Returns

Besides the greater upward bias in rebalanced vs. buy-and-hold return, it is useful to step back and think about what each of them actually measures. As noted by Asparouhova, Bessembinder, and Kalcheva (2013), rebalanced return represents the return to an investor who successfully trades on noise. For the momentum portfolios, the rebalanced return thus represents not only the return from momentum trading but also the return from a perfectly successful active trading on noise – both market microstructure and behavioral noise. This implies that the investor acts as a liquidity provider (not a liquidity taker), and is able to sell at the ask if the month-end price is at the ask, and buy at the bid if the month-end price is at the bid, among other things. As further noted by Asparouhova, Bessembinder,

and Kalcheva (2013), gains and losses from such active trading on noise are zero-sum across all agents in the economy, and therefore, the return represented by rebalancing "should be interpreted as pertaining to a hypothetical subset of investors who successfully execute an active rebalancing strategy". The rebalanced return does not represent the true return for an average active momentum trader who rebalances the portfolio every month, or an active trader who is not able to successfully trade on noise as a liquidity provider.

Buy-and-hold portfolio return measures the growth of aggregate portfolio wealth. It represents the return to a trader who trades on momentum and holds the portfolio for a certain amount of time with no further active trading to rebalance the weights within the portfolio of winners (or losers) after the portfolio is formed. Thus, it represents the return from momentum only and does not confound it with the additional return from a subsequent highly successful active trading on noise.

2.4 Matching

We use matching in two ways: match a subset of losers to a subset of winners controlling for noise-induced price volatility to demonstrate the bias in rebalanced returns; and match a subset of losers (or winners) to a control sample from portfolio 5 and 6 to assess whether momentum reverses. The procedure is similar. In the example of matching losers to winners, for each potential pair, we compute the sum of the squared distance between their characteristics $\sum_i [\frac{Char_i^L - Char_i^W}{(Char_i^L + Char_i^W)/2}]^2$, and select the pair with the smallest value.[24] Characteristics are price and market value – chosen to control for noise-induced price volatility and size-related difference in expected return – at month 0. Duplicated matches are not allowed, i.e., each winner stock can only be matched to one loser stock. However, to eliminate pairs

[24] Huang and Stoll (1996) use a similar method.

whose prices and market values are extremely apart, and to obtain an unmatched subset to compare with, we employ a cutoff. That is, the match is only conducted if the pair's prices and market values are within a certain percentage of each other. We end up choosing 30% as the cutoff when matching losers to winners and 10% as the cutoff when matching losers (or winners) to their control. These cutoffs produce about half matched and half unmatched sample: 50% of loser is matched to a winner, and 45% of loser and 64% of winner are matched to a control. It is not surprising that the cutoff has to be wider when matching between the two extreme portfolios than between losers (or winners) to median portfolios, as their characteristics are farther apart.

Chapter 3

Results

We begin with the long-term return performance of the momentum portfolios over a five-year post-identification period with monthly rebalancing.[25] Then we present the alternative buy-and-hold numbers. To get a better idea of the extent of the upward bias in rebalanced returns, we match each loser to a winner. Finally, we present the results for benchmark control portfolios for both the winner and loser portfolios.

3.1 Compounded Rebalanced Returns

Table 2 presents the returns for the 10 momentum portfolios over the five-year post-identification period and the differences in the returns between the winner portfolio (# 10) and the loser portfolio (# 1). The returns are calculated by compounding the average monthly returns for each of the portfolios. The strategy implicit here is monthly rebalancing to equal weights. The returns for months 1 to 6 document the well-established momentum returns with the winner portfolio outperforming the loser portfolio by 5.58% over the six months. There is no significant difference in the returns in the subsequent six-month period (months 7 to 12), and reversals with the winner portfolio underperforming the loser portfolio in years 2 through 5,

[25] This is consistent with prior studies which present average monthly returns for the momentum portfolios over the post-identification period which implicitly assumes monthly rebalancing. While the majority of studies adopt the monthly rebalanced approach to compute portfolio returns, few adopt a mixed strategy. Chan, Jegadeesh, and Lakonishok (1996) rebalance their portfolios only at specific intervals – at the end of six months, one year, two years and three years. They essential buy and hold the portfolios within each interval and find little sign of reversals during their sample period of 1977-1993.

with a total difference of -29.54% over the following 4-year (month 13 to 60) period. The subsequent negative return more than wipes out the positive momentum return of the first six months, resulting in a total winner minus loser portfolio return of -20.77% over the entire five years (month 1 to 60).[26] A separate comparison with portfolio 6 (zero momentum portfolio) for the winner portfolio (Portfolio 10 – Portfolio 6) and the loser portfolios (Portfolio 1 – Portfolio 6) reveals that this -20.77% difference is a combination of winner portfolio underperforming portfolio 6 by 13.89% (91.97% vs. 105.86%) and loser portfolio outperforming portfolio 6 by 6.88% (112.74% vs. 105.86%), consistent with reversals for both, but with a greater reversal for winners.

3.2 Buy-and-Hold Returns

Table 3 presents the returns for the 10 momentum portfolios over the five-year post-identification period and the differences in the returns between the winner portfolio (# 10) and the loser portfolio (# 1) using a buy-and-hold strategy. The portfolio returns are calculated by first compounding the monthly returns for each stock within the portfolio, and then averaging these buy-and-hold returns across the stocks in the portfolio for each reported period, thereby

[26] Under rebalanced returns, there is another way to calculate the difference of a long-short strategy. Instead of the difference of compounded rebalanced returns over the entire holding period, i.e., $\hat{R}^W_{RB,60} - \hat{R}^L_{RB,60}$, you can compound the difference each month, i.e., $\prod_{t=1}^{60}(1 + \hat{R}^W_{RB,t} - \hat{R}^L_{RB,t}) - 1$. The trading strategy implicit in compounded difference is not only within each winner and loser portfolio, you rebalance it to be equally weighted, but also across the winner and loser portfolio, you change and make equal the portfolio value on the basis of the abnormal difference earned before. For example, if you begin with \$1 in each portfolio and end up with \$1.04 in winner and \$0.98 in loser – an abnormal profit of \$0.06 after one period. Next period, you need to (i) long and short \$1.06 in the winner and loser portfolio; (ii) and equal weight each loser and winner within the \$1.06 portfolio to earn the compounded difference profits. We present the difference of compounded rebalanced returns to be conceptually consistent with the buy-and-hold returns later. The compounded difference still suffers from the drawback of rebalanced returns because the upward bias in $\hat{R}^W_{RB,t}$ is smaller than that in $\hat{R}^L_{RB,t}$, but will produce a smaller overall bias over the entire holding period compared to the difference of compounded rebalanced returns. The compounded difference between the winner and loser portfolios for the entire 5-year period is -8.22% (vs. -20.77% of difference of compounded rebalanced returns). This magnitude of reversal is more in line with what previous studies reported.

assuming no active rebalancing of the portfolios once formed. Survivorship bias is controlled for by reinvesting the remaining proceeds, if any, of the delisted stocks back into the same portfolio.

Comparing Table 2 rebalanced returns with Table 3 buy-and-hold returns for each momentum portfolio, rebalanced returns are consistently higher than buy-and-hold returns, and the difference increases with the holding interval. This is consistent with the higher cumulative upward bias embedded in the rebalanced method. The difference is negligible for portfolios other than the ones on the loser side – portfolio 1, 2 and 3. For instance, the cumulative 5-year rebalanced return for winners is only 3.69% higher than its buy-and-hold counterpart. But for losers the rebalanced return is 28.68% higher. Because the upward bias is related to noise-induced price volatility, this suggests the bias is trivial for stocks with reasonable price and size levels, but non-trivial for loser stocks prone to high noise-induced price volatility. The summary statistics in Table 1 confirms this as losers are on average lower-priced ($10.56) and have a smaller market value ($162.16 million) than winners ($28.00 and $563.99 million). It is this asymmetry in the upward bias in rebalanced returns that is central to the documented winner over loser reversal.

Comparison of the winner and loser difference in buy-and-hold returns in Table 3 with the rebalanced returns in Table 2 reveals a stronger momentum but little reversal afterwards. The winner portfolio outperforms the loser portfolio by 7.69% for the initial six-month period (or 9.87% for the 12-month period), as compared to the momentum profit of 5.58% (5.97%) using Table 2's rebalanced returns.[27] More importantly, the (non-)reversal for the winner minus loser difference using the buy-and-hold returns is smaller in magnitude in years 2 through 5, and does not entirely wipe out the momentum returns during the first year,

[27]This is consistent with Boynton and Oppenheimer (2006) and Liu and Strong (2006) that after using buy-and-hold returns, momentum effects in the first 6 months become 70% stronger. However, they do not examine the measurement error inflated by rebalancing over the long-term as we do.

leaving a net positive return of 4.21% for the winner minus loser portfolio over the entire 5-year period. The t-test does not show any significant difference in returns for the winner minus loser portfolio over the entire five-year period, however, the sign-test and signed rank-test show a significant positive difference. This shows continuation, as opposed to reversal, of momentum. A separate comparison with portfolio 6 (zero momentum portfolio) for the winner (portfolio 10 – portfolio 6) and loser portfolios (portfolio 6 – portfolio 1) reveals that this 4.21% difference is a combination of winner portfolio underperforming portfolio 6 by about 14.22% (88.28% vs. 102.50%), and the loser portfolio also underperforming portfolio 6 by about 18.43% (84.06% vs. 102.50%).

Figures 1a, 1b and 1c illustrate the long-term trend for the rebalanced returns and the buy-and-hold returns for the loser portfolio, winner portfolio, and the winner-loser spread, respectively. The rebalanced returns of the loser portfolio trend higher relative to the buy-and-hold returns because of the cumulation of the upward bias in the rebalanced returns which is relatively high for the loser portfolio resulting from its higher volatility of prices. The rebalanced returns of the winner portfolio trend slightly lower relative to the buy-and-hold return because of two opposing forces: the upward bias in rebalanced returns which is smaller relative to the loser portfolio because of its lower volatility of prices, and the downward or negative impact on the returns caused by rebalancing which increases the weights of the stocks which reverse more during the reversal of the winner portfolio returns. Accordingly, the winner-loser spread completely reverses and then turns negative for the rebalanced returns. However, for the buy-and-hold returns, the winner-loser spread reverses only partially and remains positive at the end of five years.

3.3 Matching Winners and Losers on Size and Price

We next compare the returns of the subsets of winners and losers which are matched on price per share and size (market value of equity). Since these subsets of the winners and losers are similar in price and size, the noise-induced biases related to price per share and errors in returns, and the size-related patterns in returns are likely to be similar. Accordingly, the comparison between these two subsets allows us to better isolate the effect of the different direction of momentum between the winners and losers, and get a better estimate of the momentum returns relatively free of the rebalancing biases. Moreover, comparison of returns between the matched and unmatched subsets of both the winner and loser portfolios allows us to get a better understanding of the bias and difference in returns caused by differences in price per share and size. The matching criteria require that both the price per share and the size of the matched firm in the winner portfolio be the within +/- 30% of the price per share and size of the firm in the loser portfolio with the smallest percentage difference, respectively.

The results using the rebalanced returns for the matched and unmatched subsets of the winner and loser portfolios are presented in Table 4 Panel A, and the corresponding results using the buy-and-hold returns are presented in Table 4 Panel B. Comparison of the returns of the matched and unmatched subsets of the loser or winner portfolio allows us to better understand the extent of the upward bias in the rebalanced returns. The rebalanced returns for the unmatched loser subset continue to be higher as compared to the matched loser subset, consistent with the greater upward bias in rebalanced returns for lower-priced stocks. The relatively large magnitude of the difference in this upward bias can be inferred by the large difference in the returns over the five-year period for the two subsets (129.70% vs.

96.94%).[28] The noise-induced bias in rebalanced returns is further confirmed by examining the results using buy-and-hold returns of the unmatched and matched subsets of the loser portfolio in Panel B, which show negligible difference in the five-year returns (81.79% vs. 85.17%). The returns for the subperiods continue to be somewhat different, which could be related to the marginally greater momentum for the unmatched loser subset (-39.88% vs. -36.28%), or its larger average size (223.18 million vs. 144.13 million).

Comparison of the rebalanced returns of the matched and unmatched subsets of the winner portfolio in Panel A confirms the greater upward bias in rebalanced returns related to the lower price and size, and thereby the higher noise-induced volatility of the matched winner subset. It is noteworthy that this difference is substantially lower for the winner subsets as compared to the loser subsets, suggesting that the magnitude of this bias is particularly severe for stocks with prices below $10.00, and may not be as severe for higher prices. Comparison of the buy-and-hold returns of the matched and unmatched subsets of the winner portfolio in Panel B shows very small differences in returns (about 0.5%) over the six-month or annual subperiods despite the differences in price and size, further confirming the appropriateness of using buy-and-hold returns for longer period returns.

Comparison of the returns of the matched subsets of the winner minus loser portfolio allows us to better understand the long-term pattern of momentum returns after controlling for the upward bias in rebalanced returns. The matched subsets are similar in price and size with the differences in the range of +/- 2 to 3%. A comparison of the returns for the matched subsets for the six-month period from months 1 through 6 confirms the presence of momentum, with the matched loser subset earning 8.26% less than the matched winner subset (2.17% vs. 10.43%). For the next six-month period, the momentum continues, but with a smaller

[28] Though not reported in the Table, the first-month return for the unmatched subset with the lower average price is 2.28% as compared to 0.80% for the matched subset with the higher price despite similar returns in the formation period, consistent with the market microstructure/bid-ask spread induced upward bias in the returns in the first month after portfolio formation.

difference of 1.84%. Starting in year 2, the pattern reverses with the loser subset earning about 2-4% more than the winner subset every year. Accordingly, the return for the entire five-year period from month 1 to 60 shows almost identical returns for the two subsets. This is in contrast with the rebalanced results in Table 2 where without controlling for volatility, losers outperform winners by 20.77% for the entire 5-year period. These results are much closer to the results of the two subsets using the buy-and-hold returns in Panel B of the Table. The momentum is somewhat greater with marginally higher differences in returns for the first year between the winner and the loser subsets. More importantly, the total return over the five-year period is marginally lower for the loser subset as compared to the matched winner subset, suggesting that not all of the momentum returns are subsequently reversed.

Figures 2a, 2b and 2c illustrate the long-term trend for the rebalanced returns for the unmatched and matched subsets of the loser portfolio, winner portfolio, and the winner-loser spread, respectively. The rebalanced returns of the matched loser subsets trend lower relative to the unmatched subset because of its lower upward bias in the rebalanced returns resulting from its lower noise-induced volatility of returns. The rebalanced returns of the matched winner subset trend only slightly higher relative to the unmatched subset because the upward bias is relatively small for the winner portfolio. Accordingly, the winner-loser spread completely reverses for the unmatched subsets and then turns negative. However, for the matched subsets, the winner-loser spread reverses but does not turn negative.

The key insights from the examination of the results of matched and unmatched subsets are that (i) a significant portion of the differences in the results for the rebalanced portfolios for the winners and losers are a result of the differences in the upward bias in the rebalanced returns arising from differences in their average price per share, and thereby the different volatility in returns; (ii) using buy-and-hold returns for matched subsets of winner and loser portfolios, only a part, and not all of the momentum return is reversed. In the following sec-

tion, we will examine in more detail the reversals for winner and loser portfolios separately, by matching them with benchmark control portfolios with no momentum.

3.4 Losers Relative to Matched Control Portfolios with No Momentum

We next compare the returns of the subsets of winner and loser portfolios with their respective control portfolios of stocks with no momentum which are matched on price per share and size (market value of equity). Since the control portfolios with no momentum are matched on price and size to their respective winner and loser subsets, the noise-induced biases related to price per share and errors in returns are likely to be similar, and the size-related patterns in returns are likely to be similar. Accordingly, the comparison and the difference in returns for the matched subsets of winners and losers and their respective benchmark portfolios allow us to get a better understanding of the momentum and reversals, separately for winners and losers, and relatively free of market microstructure and rebalancing biases. The matched control subsets of stocks for winner and loser portfolios are selected from portfolios 5 and 6 which exhibit no momentum in the corresponding identification period (months -6 through -1), and the matching criteria requires that both the price per share and the size of the matched control firm are within +/- 10% of the price per share and size of the sample stocks in the winner and loser portfolios, respectively, with the smallest percentage difference. We are able to successfully match 45% of the losers, which we refer to as the matched subset of the loser portfolio, and 64% of the winners, which we refer to as the matched subset of the winner portfolio.

The results for the matched and the unmatched subsets of the loser portfolio and the corresponding matched and unmatched subsets of portfolios 5 and 6 (benchmark control portfolios

with no momentum) are presented in Panel A of Table 5 using rebalanced returns, and in Panel B of Table 5 using buy-and-hold returns. Using rebalanced returns, the matched loser subset earns a return of only 2.39% in the six-month period from months 1 through 6, which is about 6.3% less than the return of 8.72% for the matched control subset with no momentum, suggesting that losers continue to underperform their benchmark control portfolio with no momentum by about 1% per month for the first six months after formation. For the next six months, the underperformance of the matched loser subset relative to its benchmark is about 3.6% (5.44% vs. 9.08%), suggesting that losers continue to underperform their benchmark by about 0.5% per month in the subsequent six months. The compounded one-year return from months 1 through 12 for the matched loser subset is 7.84%, which is about 10.5% less than the 18.38% for the price- and size-matched control subset with no momentum.

The returns for all of the portfolios are lower using buy-and-hold returns (Panel B of the Table) as compared to rebalanced returns because of the upward bias in the rebalanced returns. However, the differences in returns are similar, and the results are overall qualitatively similar when we look at the buy-and-hold returns for the matched loser subset and its benchmark control portfolio. The underperformance of the matched loser subset relative to its benchmark control portfolio is 7.23% for the first six months, 3.66% for the next six months, and 11.32% for the entire first year using buy-and-hold returns. These results provide clear evidence of continued underperformance of about 10% for loser stocks for one year, with 2/3 of the underperformance in the first six months, and the remaining 1/3 underperformance in the subsequent six months.

The returns for years 2, 3, 4, and 5 show small differences in returns for the matched loser subset relative to its benchmark control portfolio using rebalanced returns (Panel A) and buy-and-hold returns (Panel B), with less than 0.5% underperformance (insignificant) in Year 2, and about 1% outperformance (significant for rebalanced but insignificant for buy-

and-hold) for years 3, 4 and 5. Overall, for years 2 through 5, there is no evidence of any meaningful underperformance (continuation) or outperformance (reversal) of the momentum of the loser portfolio using a year-by-year comparison of the returns of the matched loser subset and its benchmark control portfolio using both rebalanced returns and buy-and-hold returns. Thus, it appears that the momentum in loser stocks lasts for about 12 months with relatively greater intensity in the first six months and that there is no reversal.

Comparison of the longer period returns for the four-year period from years 2 through 5 (months 13 through 60) using rebalanced returns (Panel A) and buy-and-hold returns (Panel B) for the matched loser subset and its benchmark control portfolio provides evidence consistent with the year-by-year analysis. There is no meaningful or significant difference in the returns between the matched loser subset and its benchmark control portfolio for the four-year period from months 13 to 60 suggesting that there is no continuing momentum beyond the first year, and more importantly, that there is no reversal of the first-year underperformance. This evidence of absence of reversals for the loser portfolio is not consistent with overreaction to negative news as a possible cause of the momentum for the loser portfolio. Our analysis suggests that the previously documented evidence of reversals of momentum for the loser portfolio was a statistical artifact of a combination of using rebalanced returns instead of buy-and-hold returns, and the lack of appropriate control for the relatively large upward bias in rebalanced returns related to lower price per share and size, and thereby the higher noise-induced volatility of loser stocks.

Comparison of the longer period returns for the entire five-years (months 1 through 60) using rebalanced returns (Panel A) and buy-and-hold returns (Panel B) for the matched loser subset and its benchmark control portfolio also provides evidence consistent with the year-by-year analysis. The underperformance of the matched loser subset relative to its benchmark control portfolio magnifies from about 10.54% (11.32%) for the rebalanced re-

turns (buy-and-hold returns) in the first year to 21.46% (19.47%) by the fifth year because of the compounding effect of the lower returns in the first year, and not because of any continuing underperformance beyond the first year. Rough estimates of the five-year buy-and-hold returns for the matched loser subset and its benchmark control portfolio obtained by compounding the first-year return (months 1 through 12) and the subsequent four years (months 13 through 60) are about 89% (compounding of 6.55% and 77.14%) and 108% (compounding of 17.87% and 76.83%), respectively. Thus, an underperformance of about 11% in the first year can be magnified to about 19% by the fifth year, despite no meaningful differences in returns beyond the first year.

3.5 Winners Relative to Matched Control Portfolios with No Momentum

The results for the matched and the unmatched subsets of the winner portfolio and the corresponding matched and unmatched subsets of portfolios 5 and 6 (benchmark control portfolios with no momentum) are presented in Panel A of Table 6 using rebalanced returns, and in Panel B of Table 6 using buy-and-hold returns. Using rebalanced returns, the matched winner subset earns a return of 10.31% in the six-month period from months 1 through 6, which is about 2.5% more than the return of 7.87% for the matched control subset with no momentum, suggesting that winners continue to outperform their benchmark control portfolio with no momentum by about 0.5% per month for the first six months after formation. However, in the next six months there is no outperformance of the matched winner subset relative to its benchmark, but instead, there is a relatively small underperformance of about 1% (8.15% vs. 7.22%), suggesting that the higher momentum returns for winners may have started to reverse. This is confirmed by the returns for years 2 and 3 for the two portfolios.

The matched winner subset underperforms its benchmark control by about 3.7% (12.94% vs. 16.68%) in year 2, and by about 2.7% (14.46% vs. 17.17%) in year 3. The returns for all of the portfolios are lower using buy-and-hold returns as compared to rebalanced returns because of the upward bias in the rebalanced returns. However, the differences in returns are similar, and the results are overall qualitatively similar when we look at the buy-and-hold returns for the matched winner subset and its benchmark control portfolio in Panel B of the Table. The outperformance of the matched winner subset relative to its benchmark control subset is 2.54% for the first six months, reversing into an underperformance of 0.54% for the next six months, and underperformance of 2.52% in year 2 and underperformance of 2.30% in year 3. These results provide clear evidence of relatively small outperformance of about 0.5% per month for the first six months for winners, followed by a reversal over the next 2 and ½ years. This is consistent with overreaction to positive news as a possible source of momentum for winners, and is in stark contrast to the momentum for losers which is larger in magnitude, lasts longer and does not reverse.

The returns for years 4 and 5 show small differences in returns for the matched winner subset relative to its benchmark control subset using rebalanced returns (Panel A) and buy-and-hold returns (Panel B), with about 1% underperformance (mostly insignificant). Overall, for years 4 and 5, there is no evidence of any meaningful outperformance (continuation) or underperformance (reversal) of the momentum of the winner portfolio using a year-by-year comparison of the returns of the matched winner subset and its benchmark control subset using both rebalanced returns and buy-and-hold returns for years 4 and 5.

Comparison of the longer period returns for the 4-year period from years 2 through 5 (months 13 through 60) and the entire 5-year period (months 1 through 60) using rebalanced returns (Panel A) and buy-and-hold returns (Panel B) for the matched winner subset and its benchmark control subset provides evidence consistent with the year-by-year analysis. Using

rebalanced returns, there is a relatively large and significant underperformance in the returns for the matched winner subset relative to its benchmark control subset for the 4-year period (months 13 through 60) and the five-year period (months 1 through 60), consistent with the documented reversal in years 2 and 3, magnifying to a difference of 16.67% in the years 2 through 5, and to 17.20% for the entire five-year post period. The results are qualitatively similar using buy-and-hold returns in Panel B with the underperformance of the winner subset relative to its benchmark control of 14.67% and 14.85% for the 4 and 5-year periods, respectively. The magnitude of the underperformance for the winner subset relative to its benchmark for the entire five-year post period is consistent with overreaction to positive news not just in the immediate post-identification period, but also with possible overreaction in the identification period. Figures 3a and 3b illustrate the long-term trend for the return spread between the matched subset of winners (and losers) over its respective control sample.

Overall, the separate comparison of the returns for the winner and loser subsets matched on price and size with their respective benchmark control portfolios document the following new results which contribute to our better understanding of the momentum phenomenon.

- There is a stark asymmetry in how losers and winners behave long term after comparing their returns with their respective benchmark control portfolios with no momentum.
- Momentum for loser stocks persists for about one year with approximately 1% per month lower returns in the first six months as compared to the matched control portfolio, and approximately 0.5% per month lower returns in the subsequent six months.
- These lower returns for the losers do not reverse. The results are consistent with the notion that momentum returns amongst losers are driven by under-reaction to negative news and suggest that investors hold on to losers for too long.

- At the other end of the scale, momentum for winner stocks persists only for six months and is smaller in magnitude, about 0.5% higher returns per month only for the first six months.
- More importantly, they reverse over the next 2 and 1/2 years completely wiping out the higher returns of the first six months and a part of the higher identification period return.
- The results are consistent with the notion that the higher momentum returns of the winners are an over-reaction to the positive news/higher returns in the immediate post-identification period and the identification period, and are potentially a destabilizing effect of momentum trading.

The results also highlight the need for examining losers and winners separately, matching each with their respective control portfolios with no momentum and then examining the differences, and using buy-and-hold returns, especially for the longer period and for stocks with higher return volatilities such as the extreme portfolios.

Chapter 4

Survivorship Bias

We discuss an issue that is largely overlooked in the momentum literature - the issue of survival and its implications for long-horizon returns. Figure 4 tracks the percentage of surviving stocks within each momentum portfolio over time. Since we hold portfolios at month 0, every portfolio starts with a 100% survival rate. Nevertheless, what happens after the formation paints a very different picture for each momentum portfolio. Regardless of the sub-periods, non-surviving disproportionately affects the winner and loser more than the other portfolios. Between the two extreme portfolios, loser has the lowest survival rate. Taking the entire sample period (Figure 4a) as an example, 8% of loser and 6% of winner exit the sample by month 6, and the number increases to 15% for loser and 10% for winner by month 12. And by month 60, almost half of the loser and one-third of the winner do not survive. This is in contrast with other less extreme portfolios, where the survival rate is much higher – 76% of portfolio 5 is still maintained by month 60. As we move through different sub-periods (Figures 4b, 4c and 4d), the problem of non-surviving becomes more severe. Not only all portfolios have lower survival rates during the later periods, but the effect is also more pronounced for the winner and especially for the loser portfolio. Over the most recent 1990 – 2016, 60% of losers and 40% of winners disappear before the end of month 60.

To examine the potential bias due to the changing sample over time, we look at the reasons that stocks within each portfolio drop out. This is indicated by the delisting code recorded in

the CRSP file. Four major delisting codes are mergers, exchanges, liquidations and dropped, where "dropped" generally means delisting due to bad performance such as bankruptcy. We present the frequency and return associated with each delisting code for each momentum portfolio in Table 7. Among the stocks that delist, there is a stark contrast in terms of why they delist across winner and loser portfolios. The majority of losers (56%) delist due to bad performance while this only happens to 26% of winners. The majority of winners (60%) delist because of mergers while only 30% of losers get acquired. In addition, the returns earned for "merged" and "dropped" delistings are vastly different. On average, merged stocks enjoy a positive return (from 3% to 5%) while dropped stocks suffer a negative return (from -25% to -35%).

Given that relatively large proportions of winner and loser exit the sample, we discuss how rebalancing and buy-and-hold handle sample survival.[29] Under rebalancing, we re-form an equal-weighted portfolio every month. When there are stocks that delist, rebalancing automatically distributes equal investments in the remaining securities. In other words, rebalancing takes the portfolio value at the end of each month and equally invests that in the surviving securities. Under buy-and-hold, we average the holding period return for each security. Because non-surviving stocks only have holding period returns up to the month they delist, it is important to account for how we use the value left in the position of the delisted stocks.[30] The literature usually adopts one of the following ways – reinvesting it in the risk-free security, a market index, or the same portfolio. To be conceptually consistent with the reinvesting assumption under rebalancing, our main buy-and-hold results distribute the delisted wealth back into the portfolio. Specifically, after a stock delists, we replace its

[29]Specifically, we address what happens after stocks are delisted, not delisting returns themselves. Papers like Eisdorfer (2008) and Huynh and Smith (2016) look at how delistings affect momentum returns during the holding period.

[30]Obviously adjusting for what happens after delisting will not matter if the delisting return is -100%, i.e., there is no value left in the position of the delisted stock. However, based on Table 7, the average delisting return is in all cases well above -100%.

missing return until the end of the five-year holding period with the monthly portfolio return[31]. We also analyze another option where the delisted wealth is reinvested in a randomly selected stock in the portfolio.

In order to highlight the importance of appropriately controlling for the survivorship bias, we present the results for only the surviving stocks using rebalanced returns (Table 8) and buy-and-hold returns (Table 9). Please note that the results for the rebalanced returns in Table 2 implicitly assume that the proceeds, if any, of the delisted stocks are reinvested in the remaining stocks. The results for the buy-and-hold returns (Table 3) explicitly do the same. Thus, we have controlled for the survivorship bias in Tables 2 and 3, and we are reporting the results for the surviving stocks in Tables 8 and 9 with the survivorship bias simply to illustrate the magnitude and asymmetric nature of the bias, and to underscore the importance of controlling for it.

The results using the rebalanced returns but for surviving stocks only (presented in Table 8), as expected, show higher returns for all portfolios. The differences are substantial for the loser portfolio, substantially smaller in magnitude for the winner portfolio, and negligible to extremely small for portfolios 5 and 6. The loser portfolio return for surviving stocks only for the six-month period from month 1 through 6 is 11.26% as compared to only 4.73% when we include non-surviving stocks also (Table 2). The corresponding numbers for the winner portfolio are 12.30% vs. 10.32%, and for portfolio 6 are 8.15% vs. 7.94%. Similarly, the five-year return for the surviving stocks only for the loser portfolio is 201.19%, as compared to 112.74% including non-surviving stocks. The corresponding numbers are substantially closer for the winner portfolio at 110.04% vs. 91.97%, and even closer for portfolio 6 at 107.80% vs. 105.86%. Accordingly, the results for surviving stocks only show negligible momentum and very large reversals with rebalanced returns.

[31] We follow Liu and Strong (2006) in computing the decomposed monthly buy-and-hold portfolio returns.

The results using buy-and-hold returns for surviving stocks only (presented in Table 9) reveal similar patterns, albeit with smaller differences between surviving and all stocks. The loser portfolio return for surviving stocks for the six-month period from month 1 through 6 is 9.15% as compared to only 2.52% when we include non-surviving stocks also (Table 3). The corresponding numbers for the winner portfolio are 12.11% vs. 10.20%, and for portfolio 6 are 8.04% vs. 7.76%. Similarly, the five-year return for the surviving stocks only for the loser portfolio is 122.09%, as compared 84.06% including non-surviving stocks. The corresponding numbers are substantially closer for the winner portfolio at 94.26% vs. 88.28%, and even closer for portfolio 6 at 98.49% vs. 102.50%. Accordingly, the results for surviving stocks only show negligible momentum and very large reversals with the buy-and-hold returns also.

The results of this chapter show that the survivorship bias is very large for the loser portfolio, substantially smaller in magnitude, nevertheless meaningful, for the winner portfolio, and almost negligible for portfolios with little or no momentum. The results also underscore the need for appropriate control for survivorship bias, which has been accomplished for the results presented in Tables 2 and 3.

Chapter 5

Additional Tests to Confirm the Direction and Magnitude of the Bias

In the first three sections, we discuss the results of additional robustness tests to confirm the direction and the magnitude of the noise-induced bias in the rebalanced returns using three proxies for noise – price, idiosyncratic volatility and Amihud (2002) illiquidity measure. We form tercile sub-portfolios using these noise proxies within each momentum decile, and compare each tercile's rebalanced returns with the corresponding buy-and-hold returns. Similar to our matching results in Section 3.3, our main predictions are i) within each momentum portfolio, the tercile sub-portfolio that has the highest noise level – lowest price, highest idiosyncratic volatility and highest Amihud illiquidity measure – will exhibit the highest noise-induced upward bias in the rebalanced return; ii) the tercile sub-portfolios would show buy-and-hold returns that are similar, or in line with what the literature has documented[32]. Section 5.4 is devoted to the post-decimalization period, Section 5.5 to an alternative portfolio construction method – value weighted portfolios that are also effective in reducing the rebalancing bias[33], and we finish with Section 5.6 of other robustness tests.

[32]Some of these proxies are documented to affect the cross-section of returns, in addition to the noise effect. For instance, Ang, Hodrick, Xing, and Zhang (2006) and Amihud (2002) show that stocks with higher idiosyncratic volatility and lower Amihud measure are associated with lower future returns, respectively. This raises the possibility that these measures represent risk factors, in addition to affecting noise-induced bias in rebalanced returns.

[33]See Asparouhova, Bessembinder, and Kalcheva (2013).

5.1 Price Terciles

The results for the buy-and-hold returns for the price tercile sub-portfolios within momentum portfolio 1 (loser portfolio), 2, 6, 9 and 10 (winner portfolio) are presented in Panel A of Table 10, and the corresponding results using the rebalanced returns are presented in Panel B of the Table. The price tercile sub-portfolios are formed based on the price as of the end of formation month (i.e., month -1). In addition to the extreme loser and winner portfolios, we present the results for portfolios 2 and 9 because sorting on price for portfolios 1 and 10 leads to an inadvertent sort on momentum at the same time. Accordingly, the difference in returns between the tercile sub-portfolios for these two portfolios would be affected by both the noise-induced bias and the difference in momentum. However, price tercile sub-portfolios within portfolios 2 and 9 exhibit similar negative and positive momentum, respectively, across the sub-portfolios.[34] This allows us to isolate the effect of the noise-induced bias better. We present the results for the price tercile sub-portfolios within portfolio 6 also because this portfolio exhibits no momentum with an average six-month return of about 6.00%. Examination of the price tercile sub-portfolios within portfolio 6 allows us to get an idea about the bias free of any momentum.

The mean and the median prices for the lowest price tercile within portfolio 6 - the portfolio with no positive or negative momentum - are \$8.29 and \$8.37, respectively, while the corresponding numbers for the highest price tercile are \$70.18 and \$39.33, respectively. The 60-month buy-and-hold returns in Panel A for the lowest price tercile sub-portfolio and the highest price tercile sub-portfolio are 93.44% and 80.22%, respectively, for a difference of about 13% over the 5 years. This suggests that price may be a proxy for a risk factor, with lower-priced stock being riskier, and therefore, earning a higher risk premium. This

[34]The difference in the formation period returns between the highest and lowest price terciles for momentum portfolio 1 and 10 are 7.43% and -12.01%, respectively, while that for momentum portfolios 2 and 9 are 0.83% and -0.26%, respectively.

difference of about 13% in the buy-and-hold returns for these two sub-portfolios magnifies to a difference of over 37% (126.74% vs. 89.54%) in the rebalanced returns as reported in Panel B because of the higher noise-induced bias in the rebalanced returns for the lower price tercile.

The difference between the buy-and-hold returns and rebalanced returns for the price sub-portfolios within momentum portfolio 2 are even larger in magnitude, wherein the mean and median price of the lowest price tercile drop below $5.00. The difference between the subsequent 60-month buy-and-hold return between the lowest and the highest price tercile of about 8.50% (83.54% vs 75.06%) reported in Panel A, increases to a difference of over 60.00% (146.74% vs. 86.40%) for the corresponding rebalanced returns in Panel B. The difference between the rebalanced and buy-and-hold returns for the highest price decile is about 11%, while the corresponding difference for the lowest price decile is about 63%. The results confirm both the direction and the extremely large magnitude of noise-induced bias in rebalanced returns for the lower-priced stocks, especially for stocks below $5.00.

The negative relation between the price and noise-induced bias in rebalanced returns is non-linear, and increases exponentially with the decline in the price. The results for the price sub-portfolios within the loser portfolio (portfolio 1) provide further confirmation of this result. The difference of about -4.50% (63.56% vs 68.19%) between the lowest price tercile in buy-and-hold returns in Panel A changes to a difference of over 73% (157.26% vs. 83.63%) in the rebalanced returns in Panel B. While the difference in both the buy-and-hold returns and the rebalanced returns across the sub-portfolios is possibly related to the difference in momentum, the extremely large difference in the difference in the buy-and-hold returns across the sub-portfolios and the difference in the corresponding rebalanced returns is indicative of the large noise-induced upward bias in the rebalanced returns related to low price. Another strong indication of the extremely large magnitude of the noise-induced bias

in rebalanced returns for the lowest-priced stocks is provided by the comparison between the buy-and-hold and rebalanced returns for the lowest price sub-portfolio within the loser portfolio. This portfolio has mean and median prices of $3.04 and $3.08, respectively. The 60-month buy-and-hold returns and rebalanced returns for this portfolio are 63.56% and 157.26%, respectively, a difference of over 93%.

Relatively smaller, nevertheless large differences are observed between the rebalanced and buy-and-hold returns for the lower price sub-portfolios for portfolios 9 and 10. Overall, the comparison of the buy-and-hold returns and rebalanced returns for the price tercile sub-portfolios within the momentum portfolios provides a strong confirmation of the large magnitude of the noise-induced bias in the rebalanced returns and its exponential increase as the price declines below $10.00 and even more so, when it declines below $5.00.

5.2 Idiosyncratic Volatility Terciles

The results for buy-and-hold returns for the sub-portfolios based on the terciles of idiosyncratic volatility (IVOL) within momentum portfolios 1 (loser portfolio), 2, 6, 9 and 10 (winner portfolio) are presented in Panel A of Table 11, and the corresponding results using the rebalanced returns are presented in Panel B of the Table. We estimate IVOL for each stock as the standard deviation of the residual from the FF-4 factor, including the momentum factor:

$$R_t - r_{f,t} = \alpha + \beta * (R_{m,t} - r_{f,t}) + s * SMB_t + h * HML_t + m * MOM_t + \epsilon_t \tag{5.1}$$

Where $IVOL_t = \sqrt{var}(\epsilon_t)$. We measure IVOL using daily data over the six months prior to the formation, i.e., [-12, -7], to avoid estimating it directly during the formation period that

is accompanied by a temporary increase in IVOL.[35]

The mean and the median IVOL for the lowest IVOL sub-portfolio within portfolio 6 - the portfolio with no positive or negative momentum - are 0.12 and 0.12, respectively, while the corresponding numbers for the highest IVOL sub-portfolio are 0.38 and 0.33, respectively. For the IVOL terciles, we expect the noise-induced volatility in the rebalanced returns to be higher for the higher IVOL tercile. The 60-month buy-and-hold returns in Panel A for the lowest IVOL tercile and the highest IVOL tercile are 86.00% and 87.88%, respectively, for a difference of about -2% over the 5 years. This difference of about -2% in the buy-and-hold returns for these two sub-portfolios magnifies to a difference of about -22% (97.00% vs. 118.86%) in the rebalanced returns in Panel B because of the higher noise-induced bias in the rebalanced returns of the higher IVOL sub-portfolio.

The difference between the buy-and-hold returns and rebalanced returns for the IVOL sub-portfolios within momentum portfolio 2 are even larger in magnitude, wherein the mean and median IVOL of the highest IVOL sub-portfolio increase to 0.05 and 0.045, respectively. The difference between the subsequent 60-month buy-and-hold return between the lowest and the highest IVOL tercile of about +5.00% (81.72% vs 77.06%) in Panel A, turns into a negative difference of about -32.00% (96.96% vs. 129.34%) for the corresponding rebalanced returns in Panel B. The difference between the rebalanced and buy-and-hold returns for the lowest IVOL decile is about 15%, while the corresponding difference for the highest IVOL decile is about 52%. The results confirm both the direction and the extremely large magnitude of noise-induced bias in rebalanced returns for the higher IVOL stocks. Another strong indication of the extremely large magnitude of the noise-induced bias in rebalanced returns for the highest IVOL stocks is provided by the comparison between the buy-and-hold returns and rebalanced returns for the highest IVOL sub-portfolio within the loser portfolio.

[35]The results are qualitatively similar when IVOL terciles are based on IVOL estimated directly over the formation period (month [-6, -1]), or over an even earlier period in the pre-formation (month [-18, -13]).

This portfolio has a mean and median IVOL of 0.062 and 0.055, respectively. The 60-month buy-and-hold returns and rebalanced returns for this portfolio are 53.37% and 128.58%, respectively, a difference of over 75%.

Relatively smaller, nevertheless large differences are observed between the rebalanced and buy-and-hold returns for the highest IVOL sub-portfolios for portfolios 9 and 10. Overall, the comparison of the buy-and-hold returns and rebalanced returns for the IVOL tercile sub-portfolios within the momentum portfolios provides a strong confirmation of the large magnitude of the noise-induced bias in the rebalanced returns for stocks with high idiosyncratic volatility.

5.3 Amihud Illiquidity Measure Terciles

The results for buy-and-hold returns for the sub-portfolios based on the terciles Amihud illiquidity measure (ILLIQ) within momentum portfolios 1 (loser portfolio), 2, 6, 9 and 10 (winner portfolio) are presented in Panel A of Table 12, and the corresponding results using the rebalanced returns are presented in Panel B of the Table. We estimate Amihud for each stock as the average of the price impact of one-million dollar of trading volume, i.e., $Average(\frac{|r_t|}{Volume_t}) * 10^6$. It is measured using the same data as IVOL - daily data over the six-month pre-formation period [-12, -7].

The mean and the median ILLIQ for the lowest ILLIQ sub-portfolio within portfolio 6 - the portfolio with no positive or negative momentum - are 1.62 and 1.52, respectively, while the corresponding numbers for the highest ILLIQ sub-portfolio are 39.45 and 26.64, respectively. For the ILLIQ terciles, we expect the noise-induced volatility in the rebalanced returns to be higher for the higher ILLIQ tercile. The 60-month buy-and-hold returns in Panel A for the lowest ILLIQ tercile and the highest ILLIQ tercile are 78.83% and 97.06%, respectively, for a

difference of about -18% over the 5 years. This is consistent with the results and conclusions of prior studies suggesting that IILIQ may be a proxy for a risk factor, with higher ILLIQ stock being riskier, and therefore, earning a higher risk premium. This difference of about -18% in the buy-and-hold returns for these two sub-portfolios magnifies to a difference of about -37% (87.43% vs. 124.85%) in the rebalanced returns in Panel B because of the higher noise-induced bias in the rebalanced returns of the higher ILLIQ sub-portfolio.

The difference between the buy-and-hold returns and rebalanced returns for the ILLIQ sub-portfolios within momentum portfolio 2 are even larger in magnitude, wherein the mean and median ILLIQ of the highest ILLIQ sub-portfolio increases to 45.72 and 29.49, respectively. The difference between the subsequent 60-month buy-and-hold return between the lowest and the highest ILLIQ tercile of about -16.00% (73.36% vs 89.57%) in Panel A, increases to a difference of about -47.50% (86.21% vs. 133.82%) for the corresponding rebalanced returns in Panel B. The difference between the rebalanced and buy-and-hold returns for the lowest ILLIQ decile is about 13%, while the corresponding difference for the highest ILLIQ decile is about 44%. The results confirm both the direction and the extremely large magnitude of noise-induced bias in rebalanced returns for the higher ILLIQ stocks. Another strong indication of the extremely large magnitude of the noise-induced bias in rebalanced returns for the highest ILLIQ stocks is provided by the comparison between the buy-and-hold returns and rebalanced returns for the highest ILLIQ sub-portfolio within the loser portfolio. This portfolio has a mean and median ILLIQ of 48.44 and 32.33, respectively. The 60-month buy-and-hold returns and rebalanced returns for this portfolio are 73.00% and 133.65%, respectively, a difference of over 60%.

Relatively smaller, nevertheless large differences are observed between the buy-and-hold returns and rebalanced returns for the higher ILLIQ sub-portfolios for portfolios 9 and 10. Overall, the comparison of the buy-and-hold returns and rebalanced returns for the ILLIQ

tercile sub-portfolios within the momentum portfolios provides a strong confirmation of the large magnitude of the noise-induced bias in the rebalanced returns for stocks with low liquidity.

The results of this section provide evidence on the large magnitude of the noise-induced bias in rebalanced returns for portfolios of stocks with very low price, very high idiosyncratic volatility, and very low liquidity. Since the loser portfolio has a very higher proportion of such stocks relative to the winner and other momentum portfolios, the noise-induced upward bias in the rebalanced returns is very large for the loser portfolio, relative to the other portfolios. This large noise-induced upward bias in the rebalanced returns of the loser portfolio creates a false impression that there is a reversal of the loser portfolio returns, while in fact there is a continuation of their lower returns.

5.4 Post-Decimalization

In this section, we examine the effect of decimalization on the upward bias in rebalanced returns caused by noise-induced price volatility. As discussed earlier, noise includes any temporary deviations of observed price from the underlying value, which can take the form of price impacts from order imbalances, microstructure frictions such as bid-ask spreads, price discreteness and non-synchronous trading, and behavioral factors. Decimalization is expected to reduce the bid-ask spreads especially for high liquidity stocks and it would be instructive to examine the extent to which the noise-induced bias in rebalanced returns is reduced.

We begin by examining the buy and hold and rebalanced returns for the momentum portfolios in the post-decimalization period from April 2001[36] to December 2016. The results

[36]Nasdaq fully adopted decimalization on April 9, 2001, preceded by NYSE which fully decimalized on January 29, 2001.

for the buy-and-hold returns for the post-decimalization period are presented in Table 14, and the corresponding results using the rebalanced returns are presented in Table 15. The average buy-and-hold returns for the entire post-decimalization period from April 2001 to December 2016 do not exhibit any significant momentum or reversals for the portfolios. This period includes the 2007-09 recession and the associated decline of about 56% in the S&P 500 from October 9, 2007 to March 9, 2009. As prior studies have shown, there is no momentum during the periods when the stock markets are down, and it appears that the momentum for the entire post-decimalization period may have been affected by the recession in 2007-09 period and the associated large stock market decline. Nevertheless, the 60-month post-formation rebalanced return of 76.30% for the loser portfolio in Table 15 is about 25% higher than the corresponding buy-and-hold return of 51.77% in Table 14, indicative of the continuation of the large noise-induced bias in rebalanced returns in the post-decimalization period. For the winner portfolio, the difference between the 60-month post formation rebalanced returns and the buy-and-hold returns is substantially lower at about 14% (61.37% vs. 47.88%).

Since the entire post-decimalization period includes a 56% drop in the value of the S&P 500 in the 2007-09 period, and it took another four years (till 2013) to recover to the 2007 levels, we also examine the returns for the momentum portfolios in the post-decimalization period before the stock market decline, from April 2001 to August 2007. The results for the buy-and-hold returns for the post-decimalization period are presented in Table 16, and the corresponding results using the rebalanced returns are presented in Table 17. The average buy-and-hold returns for this relatively short pre-recession post-decimalization period exhibit significant momentum for the loser portfolio with a return of -13.42% for the 6-month post-formation period, while the winner portfolio earns a buy-and-hold return of -1.63%, a small reversal of the formation period returns. The difference between the winner and

loser portfolio is a significant 11.46% for the 6-month post formation period. The 60-month post-formation rebalanced return of 122.96% for the loser portfolio in Table 17 is about 71% higher than the corresponding buy-and-hold return of 51.77% in Table 16, indicative of the continuation of the large noise-induced bias in rebalanced returns in the post-decimalization period. This large difference between the rebalanced returns and buy-and-hold returns for the loser portfolio is larger than the corresponding difference for the entire period as presented in Tables 2 and 3, but is similar to the corresponding difference for the lowest price decile in the loser portfolio as presented in Table 10. This can be potentially explained by the observation that the average price of the stocks in the loser portfolio in this post-decimalization period is only \$3.46, which is less than half of the average price of \$10.56 for the loser portfolio for the entire period from 1951 to 2016 (Table 13), but is similar to the average price of \$3.04 for the lowest price decile (Table 10) of the loser portfolio for the entire period. For the winner portfolio, the difference between the 60-month post formation rebalanced returns and the buy-and-hold returns is lower at about 37% (132.71% vs. 97.98%). The average price for the stocks in the winner portfolio for this post-decimalization period is \$14.53, while the average price for the winner portfolio for the entire period is \$28.00.[37]

The results for the post-decimalization period suggest that the upward bias in rebalanced returns caused by noise-induced price volatility continues to be large for the low-priced stocks in the post-decimalization period.

5.5 Value-Weighted Portfolios

In this section, we present the results for the momentum portfolios using value-weighted returns and compare them to the rebalanced returns and buy-and-hold returns. We expect

[37] The average prices for the loser and winner portfolios have declined over the entire period.

the value-weighted returns to be lower than the rebalanced returns because of the upward bias in the rebalanced returns caused by noise-induced price volatility. We also expect the value-weighted returns to be lower than the buy-and-hold returns because of previously documented negative relation between size and returns and the greater initial weighting of larger firms in the momentum portfolio for the value-weighted returns as compared to the buy-and-hold returns. It is important to note that both the value-weighted returns and the buy-and-hold returns are in effect buy-and-hold returns with the only difference being the initial weighting of the portfolios. The buy-and-hold returns reported throughout the paper are based on initial equal weighting of the stocks in the momentum portfolios and the value-weighted returns are based on initial value-weighting of the stocks in the portfolios.

The results for the value-weighted returns for the momentum portfolios are presented in Table 18. As expected, the rebalanced returns in Table 2 are higher than the value-weighted returns for all portfolios and for all the reported post-formation periods because of the upward bias in rebalanced returns. The difference between the rebalanced and value-weighted returns increases with the length of the period over which the return is calculated. The difference between the rebalanced returns and value-weighted returns is the highest for the loser portfolio which has the stocks with the lowest price and size, consistent with higher bias in rebalanced returns caused by noise-induced price volatility. These results are similar to the difference between rebalanced returns and buy-and-hold returns discussed earlier in the paper.

As expected, the buy-and-hold returns for the momentum portfolios in Table 3 are higher than the corresponding value-weighted returns in Table 18, consistent with higher initial weighting of larger firms in value-weighted returns and the negative relation between size and returns. However, the returns of the winner-loser portfolio are similar for all post-formation sub periods. For example, the winner-loser return is 7.70% for the first six-month

[1,6] buy-and-hold return, and 7.40% for the corresponding value-weighted return. For the entire 60-month post formation period, the winner-loser portfolio earns 4.19% using buy-and-hold returns and 8.75% using value-weighted returns. For the individual momentum portfolios, the difference between the 60-month post-formation buy-and-hold returns and value-weighted returns are the amongst the highest for portfolios 4, 5, 6 and 7, suggesting that the initial difference in weights are the highest for these low or no-momentum portfolios and higher variability in the firm sizes within these portfolios.

We believe that the examination of the long-term returns for the momentum portfolios and the conclusions based on such an examination are better achieved using buy-and-hold returns as compared to value-weighted returns because the buy-and-hold returns with their initial equal weights better represent a typical stock in the momentum portfolio, and because the value-weighted returns depend not just upon the average size of the firms in the portfolio but are also affected by the variability in firm sizes within the portfolio.

5.6 Other Robustness

We perform other robustness tests in terms of:

- different reinvesting assumptions for delisted stocks in the buy-and-hold portfolio: reinvesting at 0%, risk-free rate, or a randomly-selected stock within the same portfolio.
- different matching characteristics: matching on price only, or on price, market value and book-to-market ratio.
- different cutoffs for the matching procedure: cutoff at 5%, 20% or 60%.

All analysis yields qualitatively similar results.

Chapter 6

Conclusions

Following its positive return during the first year, momentum is marked by a negative return over the next four years – as large as reversing 70% to over 100% of the initial profit. The persistence and magnitude of the negative return has long been considered as supportive of overreaction as the explanation of momentum. Considering its prominence in understanding of what drives momentum, we revisit the reversal, or more generally the long-term pattern of momentum in this paper.

We aim to show that studying momentum's long-term pattern is no easy task – the results show different patterns for rebalanced and buy-and-returns, for winners and losers, and for the surviving and non-surviving samples. The frequent used method of rebalancing portfolio every month is upwardly biased. The bias is increasing in the noise-induced price volatility and losers, due to their lower prices and smaller market values, are more prone to the bias. Losers' highly inflated rebalanced return creates the illusion that the winner-loser momentum reverses. The buy-and-hold portfolio return which is less prone to the bias shows significantly less reversal for the winner-loser return. We find similar results using rebalanced returns with a control for noise-induced price volatility, and confirm the magnitude of the bias in tercile sorting within winners and losers by different proxies of noise – price, idiosyncratic volatility, and Amihud illiquidity measure.

We also compare the return of winners and losers to their separate control samples with no momentum, and find striking asymmetries in how they behave long-term. Winner mo-

mentum is smaller in magnitude, persists only for six months, and its higher return fully reverses. This result is consistent with the notion that winner momentum in the immediate post-formation period is an overreaction to the positive returns in the formation period. Loser momentum is larger in magnitude, persists for about one year, and its lower return does not reverse in the long run. This result is consistent with the notion that loser momentum in the immediate post-formation period is a consequence of underreaction to the negative events or news in the formation period. The results provide interesting insights and implications about the potential causes of momentum and profitability of momentum trading. Existing theories that could potentially conform to the overreaction of winners and underreaction of losers include overconfidence (Daniel, Hirshleifer, and Subrahmanyam, 1998), representativeness and conservatism (Barberis, Shleifer, and Vishny, 1998), interaction between agents holding asymmetric information (Hong and Stein, 1999) and investors' asymmetric response to fund performance (Vayanos and Woolley, 2013).

Last, we show the importance of survivorship in studying the long-run performance of momentum. Relatively large proportions of winners and losers drop out of the sample for vastly different reasons with the surviving sample significantly outperforming the non-surviving sample.

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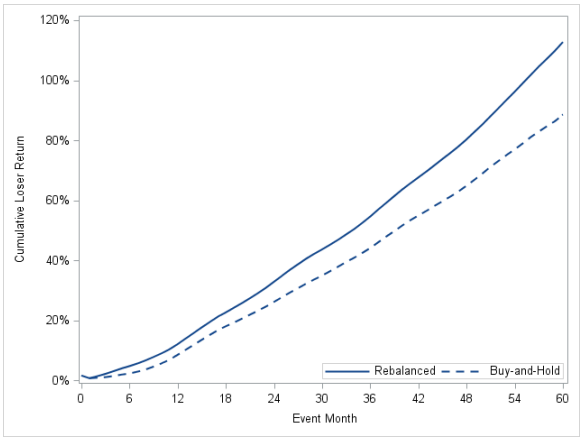
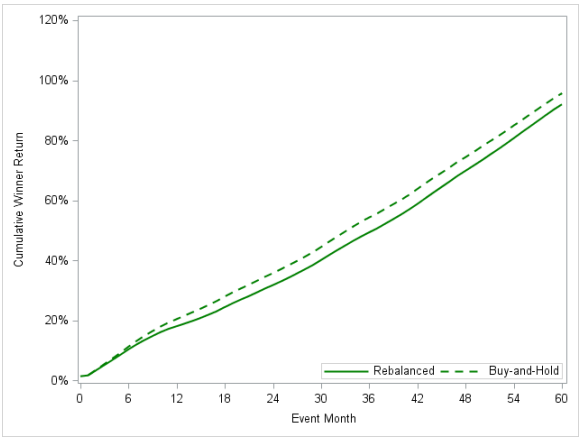
Figure 1: Cumulative Momentum Returns: Rebalancing vs. Buy-and-Hold

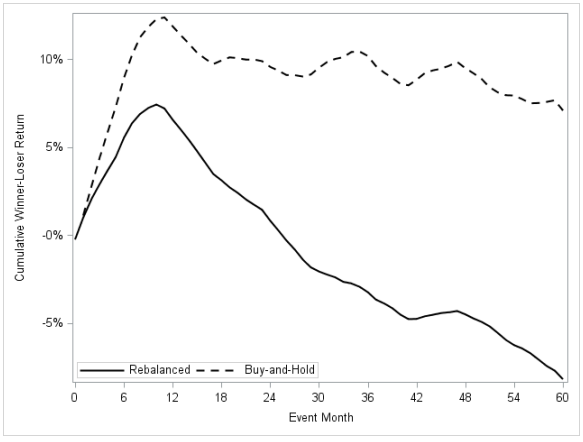
This figure shows returns of momentum winner and loser portfolios in each year after the formation for five years. We form winner and loser portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and forms the loser portfolio. Decile 10 has stocks with the highest returns and forms the winner portfolio. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Rebalanced portfolio returns, where each stock's return is averaged then compounded over time, and buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time, are shown.



(a) Loser Portfolio



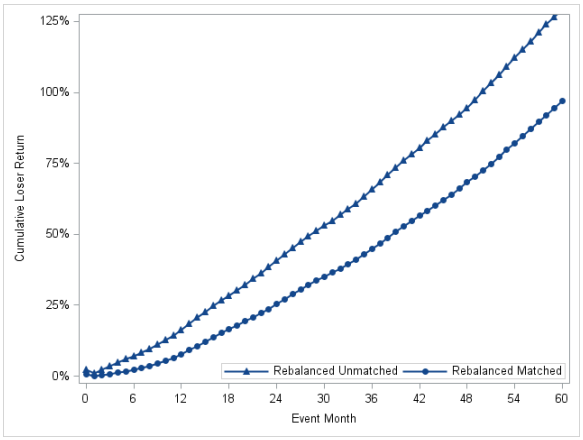
(b) Winner Portfolio



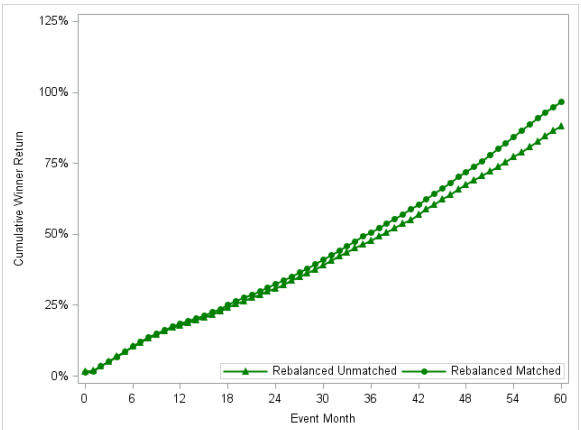
(c) Winner-Loser Spread

Figure 2: Rebalanced Cumulative Momentum Returns: Matched and Unmatched Sample

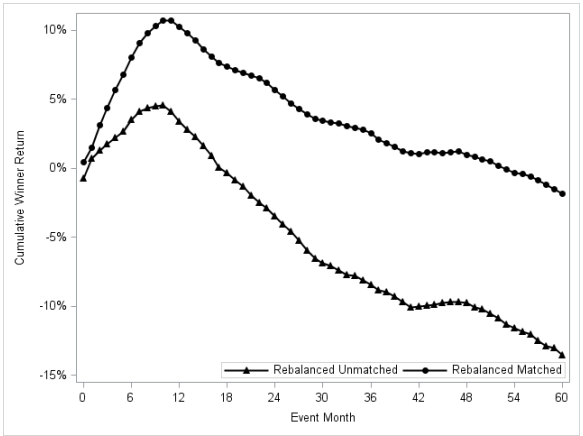
This figure shows returns of momentum winner and loser portfolios in each year after the formation for five years. We form winner and loser portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and forms the loser portfolio. Decile 10 has stocks with the highest returns and forms the winner portfolio. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. For the matching, we find a winner stock with the closest squared distance based on price and market value for each loser stock at initial month 0, as long as the winner's price and size are within -/+ 30% of those of the loser. The 30% cutoff helps to eliminate pairs whose prices and sizes are extremely apart, and gives sufficient matched and unmatched sample to compare with. We end up with half of the loser (or winner) portfolio matched and the other half unmatched. Rebalanced portfolio returns, where each stock's return is averaged then compounded over time, are shown in 2a-2c.



(a) Loser Portfolio



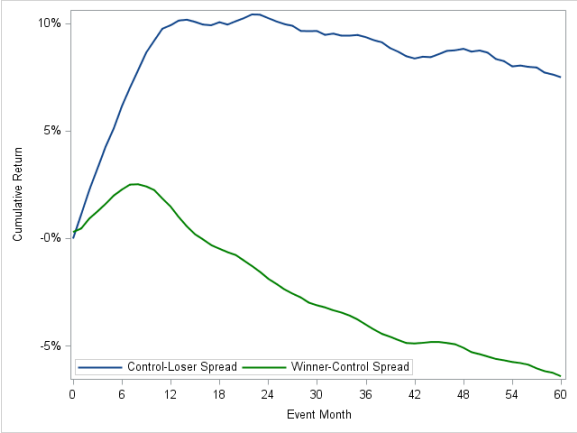
(b) Winner Portfolio



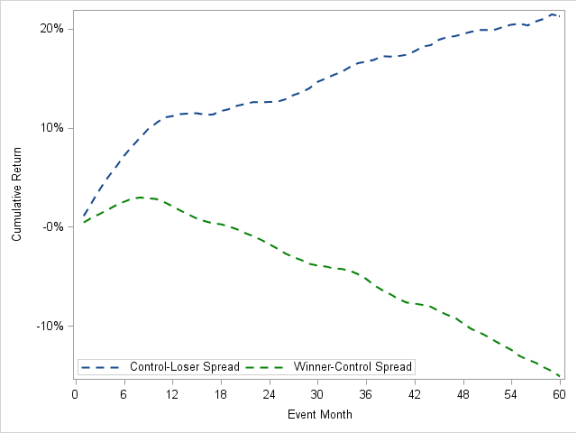
(c) Winner-Loser Spread

Figure 3: Cumulative Momentum Returns: Loser/Winner and Its Matched Control Portfolio

This figure shows the return spread of momentum winner (or loser) over its respective matched control portfolio in each year after the formation for five years. We form winner and loser portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and forms the loser portfolio. Decile 10 has stocks with the highest returns and forms the winner portfolio. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. For the matching, we find a winner (or loser) stock with the closest squared distance based on price and market value for each stock in the no-momentum portfolio (Decile 5 and 6) at initial month 0, as long as the target's price and size are within -/+ 10% of those of the match. The 10% cutoff helps to eliminate pairs whose prices and sizes are extremely apart. We end up with 45% of the losers and 64% of the winners matched. Rebalanced portfolio returns, where each stock's return is averaged then compounded over time, are shown in 3a, and buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time, are shown in 3b.



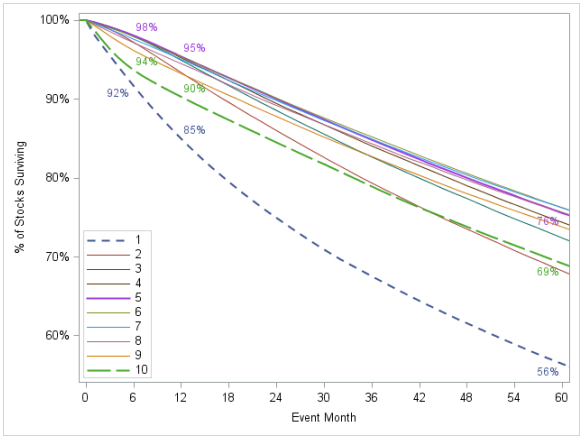
(a) Rebalanced Return



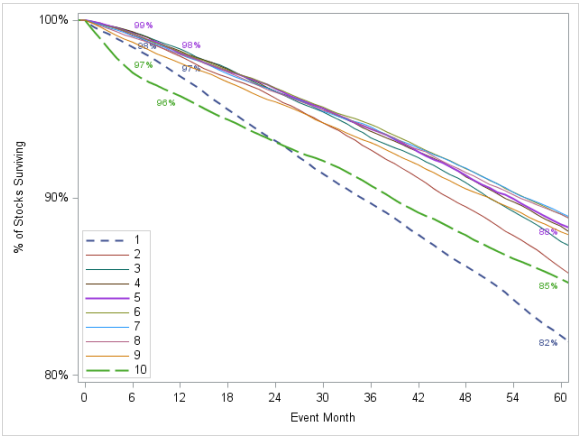
(b) Buy-and-Hold Return

Figure 4: Percentage of Surviving Stocks Across Momentum Portfolios

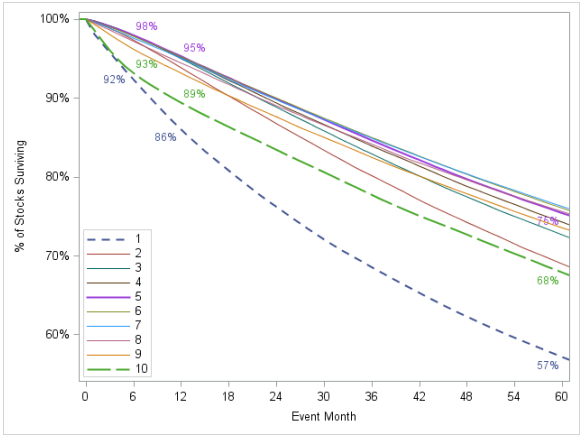
This figure shows the percentage of stocks remaining in each momentum portfolio over event time. At the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. Then we track the number of stocks remaining in each portfolio for the next 60 months and present it as a percentage of the number of stocks at month 0. The procedure is repeated each month and the percentage is averaged across the sample period.



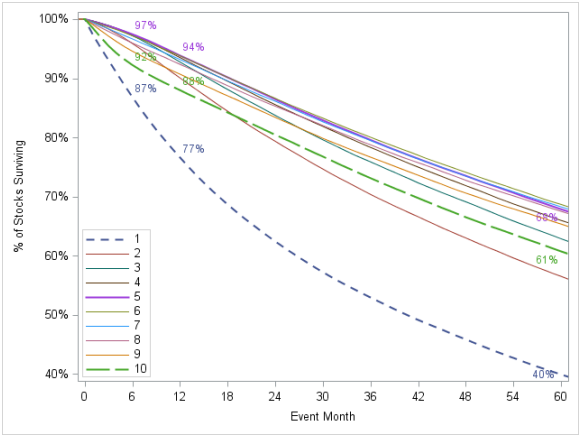
(a) Sample Period: Jun 1951 - Dec 2016



(b) Sample Period: Jan 1951 - Dec 1964



(c) Sample Period: Jan 1965 - Dec 1989



(d) Sample Period: Jan 1990 - Dec 2016

Table 1: Average Characteristics of Momentum Portfolios

This table shows the mean and median price, market value of equity, book-to-market ratio, beta, and individual monthly return standard deviation for each momentum portfolio. Momentum portfolios are formed by ranking stocks based on their past 6-month returns and grouping them into decile portfolios. Decile 1 is the loser portfolio and decile 10 is the winner portfolio. The ranking is repeated each month and each statistics is averaged across the sample period of Jun 1951 – Dec 2016. Price, market value of equity, book-to-market ratio and beta are end-of-formation month values. Book value of equity in the book-to-market ratio is defined as the book value of stockholders' equity, plus balance sheet deferred taxes and investment tax credit (if available), minus the book value of preferred stock following Davis, Fama, and French (2000). Beta is estimated against the value-weighted market return in CRSP using five-year monthly returns and requiring a minimum of 24 monthly returns. Std is estimated using available non-missing returns over the five-year holding period.

	Price_0		Market Value_0 ($ Millions)		Book-to-Market_0		Beta_0		$\text{Std}_{[1,60]}$	
	mean	median	mean	median	mean	median	mean	median	mean	median
1	10.56	7.46	162.16	27.91	0.88	0.65	1.33	1.29	20.98%	18.29%
2	15.96	11.76	463.44	58.15	0.90	0.71	1.21	1.16	16.02%	14.07%
3	24.53	14.79	741.37	82.09	0.91	0.75	1.12	1.06	13.81%	12.00%
4	29.64	17.21	999.86	105.29	0.91	0.77	1.05	0.99	12.47%	10.71%
5	31.28	19.19	1170.36	126.16	0.91	0.78	1.02	0.95	11.70%	9.99%
6	33.08	20.58	1256.75	143.77	0.92	0.79	1.01	0.94	11.31%	9.65%
7	34.13	21.64	1297.88	157.67	0.93	0.80	1.02	0.96	11.21%	9.63%
8	33.32	22.03	1256.00	161.21	0.94	0.80	1.05	0.99	11.52%	9.99%
9	30.88	21.55	1053.24	151.52	0.96	0.79	1.12	1.06	12.36%	10.91%
10	28.00	18.79	563.99	105.88	1.04	0.81	1.24	1.19	14.81%	13.44%

Table 2: Momentum Returns Over Long Run: Rebalanced Portfolio Returns

This table shows returns of momentum portfolios in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. This table presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-38.18%	4.73%	7.05%	20.40%	20.79%	18.36%	18.50%	12.06%	92.86%	112.74%
2	-20.44%	5.68%	7.66%	18.50%	19.30%	17.24%	17.78%	13.60%	88.27%	111.05%
3	-11.69%	6.52%	7.60%	17.44%	18.25%	16.16%	17.18%	14.38%	84.26%	108.86%
4	-5.15%	7.23%	7.77%	16.76%	17.38%	15.99%	16.58%	15.36%	81.66%	108.16%
5	0.56%	7.56%	7.91%	16.45%	16.99%	15.85%	15.84%	15.92%	79.49%	106.97%
6	6.17%	7.86%	8.08%	16.29%	16.45%	15.67%	15.53%	16.41%	77.50%	105.86%
7	12.34%	8.22%	8.08%	16.36%	16.30%	15.91%	15.31%	16.80%	76.96%	106.18%
8	20.10%	8.66%	8.20%	16.17%	16.15%	15.98%	14.80%	17.39%	75.19%	105.30%
9	32.22%	9.21%	8.05%	15.58%	15.99%	16.27%	14.28%	17.75%	72.90%	103.28%
10	77.27%	10.32%	7.26%	13.01%	14.51%	15.94%	13.62%	18.02%	63.33%	91.97%
Diff (10-1)	115.45%	5.58%	0.20%	-7.40%	-6.29%	-2.42%	-4.88%	5.97%	-29.54%	-20.77%
(t)	(6.65)***	(2.70)***	(-0.34)	(-2.39)**	(-1.93)*	(-0.63)	(-1.78)*	(1.36)	(-1.94)*	(-1.64)
Diff (1-6)	-44.35%	-3.12%	-1.03%	4.11%	4.35%	2.70%	2.98%	-4.36%	15.36%	6.88%
(t)	(-6.79)***	(-1.52)	(-0.37)	(1.27)	(1.09)	(0.75)	(1.12)	(-0.97)	(0.98)	(0.28)
Diff (10-6)	71.11%	2.46%	-0.83%	-3.28%	-1.94%	0.28%	-1.90%	1.61%	-14.18%	-13.89%
(t)	(6.42)***	(1.92)*	(-1.06)	(-1.85)*	(-1.46)	(0.39)	(-0.40)	(0.54)	(-1.90)*	(-1.78)*

Table 3: Momentum Returns Over Long Run: Buy-and-Hold Portfolio Returns

This table shows returns of momentum portfolios in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. This table presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-38.18%	2.52%	5.62%	16.92%	15.93%	14.69%	14.40%	8.40%	71.02%	84.06%
2	-20.44%	4.85%	7.24%	17.42%	16.74%	15.37%	14.76%	12.34%	76.25%	96.29%
3	-11.69%	6.00%	7.44%	16.92%	17.02%	14.78%	15.18%	13.73%	77.17%	100.28%
4	-5.15%	6.96%	7.72%	16.56%	16.31%	15.22%	15.31%	15.11%	77.10%	102.93%
5	0.56%	7.40%	7.85%	16.30%	16.26%	15.11%	14.82%	15.74%	76.21%	103.25%
6	6.17%	7.76%	8.14%	16.22%	15.89%	14.69%	14.62%	16.43%	74.32%	102.50%
7	12.34%	8.16%	8.11%	16.52%	15.92%	15.16%	14.39%	16.81%	74.79%	103.87%
8	20.10%	8.61%	8.37%	16.39%	15.72%	15.05%	13.87%	17.55%	72.70%	102.57%
9	32.22%	9.16%	8.21%	16.03%	15.56%	14.98%	13.48%	17.92%	70.55%	100.49%
10	77.27%	10.20%	7.52%	13.70%	14.06%	14.27%	12.31%	18.27%	60.31%	88.28%
Diff (10-1)	115.45%	7.69%	1.91%	-3.22%	-1.87%	-0.42%	-2.09%	9.87%	-10.72%	4.21%
(t)	(6.65)***	(3.85)***	(1.09)	(-1.56)	(-0.73)	(0.37)	(-0.14)	(2.56)**	(-0.73)	(0.81)
Diff (1-6)	-44.35%	-5.24%	-2.53%	0.71%	0.03%	-0.00%	-0.21%	-8.03%	-3.30%	-18.43%
(t)	(-6.79)***	(-2.81)***	(-1.62)	(0.25)	(-0.38)[38]	(-0.43)	(-0.53)	(-2.09)**	(-0.83)	(-1.26)
Diff (10-6)	71.11%	2.44%	-0.62%	-2.52%	-1.83%	-0.42%	-2.30%	1.84%	-14.02%	-14.22%
(t)	(6.42)***	(1.86)*	(-0.83)	(-1.52)	(-1.52)	(-0.15)	(-0.53)	(0.59)	(-1.93)*	(-1.84)*

[38] Occasionally the average abnormal return and its corresponding t-stat share different signs because the abnormal return is a simple time-series average while the t-stat, in order to adjust for correlation and heteroscedasticity, is based on a weighted-average with weights depend on how many firms are in the portfolio each month.

Table 4: Momentum Returns Over Long Run: Matched Winner and Loser

This table shows returns of the matched and unmatched winner and loser portfolios in each year after the formation for up to five years. We form winner and loser portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns (losers) and decile 10 has stocks with the highest returns (winners). The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. For the matching, we find a winner stock with the closest squared distance based on price and size for each loser stock at initial month 0, as long as the winner's price and size are within -/+ 30% of those of the loser. The 30% cutoff helps to eliminate pairs whose prices and sizes are extremely apart, and gives sufficient matched and unmatched sample to compare with. Panel A presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. Return t-stats are correlation and heteroscedasticity-consistent.

	Price	Market Value	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		($ Millions)	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
Panel A. Rebalanced Portfolio Returns												
1 unmatched (50%)	8.79	223.18	-39.88%	7.17%	8.51%	22.94%	22.32%	18.87%	18.59%	16.34%	100.27%	129.70%
1 matched (50%)	13.06	144.13	-36.28%	2.17%	5.67%	18.28%	19.47%	17.99%	18.07%	7.71%	86.21%	96.94%
10 matched	13.36	139.69	80.07%	10.43%	7.51%	13.55%	15.16%	16.31%	15.19%	18.45%	67.31%	96.77%
10 unmatched	40.53	890.22	75.00%	10.39%	7.05%	12.40%	13.94%	15.38%	12.72%	17.91%	59.92%	88.09%
Matched Diff (10-1)	0.30	-4.45	116.35%	8.26%	1.84%	-4.73%	-4.31%	-1.68%	-2.88%	10.74%	-18.90%	-0.18%
(t)	(17.63)***	(-14.61)***	(11.63)***	(4.45)***	(1.25)	(-2.31)**	(-1.89)*	(-0.65)	(-0.88)	(3.13)***	(-2.16)**	(-0.08)
Panel B. Buy-and-Hold Portfolio Returns												
1 unmatched (50%)	8.79	223.18	-39.88%	3.91%	5.98%	16.58%	15.57%	13.61%	13.24%	10.23%	66.74%	81.79%
1 matched (50%)	13.06	144.13	-36.28%	0.94%	5.14%	17.28%	16.68%	15.72%	15.45%	6.12%	75.39%	85.17%
10 matched	13.36	139.69	80.07%	10.09%	7.49%	13.41%	13.64%	13.68%	12.55%	18.12%	58.66%	85.58%
10 unmatched	40.53	890.22	75.00%	10.50%	7.66%	13.70%	14.25%	14.61%	12.41%	18.79%	61.67%	91.20%
Matched Diff (10-1)	0.30	-4.45	116.35%	9.14%	2.34%	-3.87%	-3.04%	-2.04%	-2.90%	12.00%	-16.73%	0.41%
(t)	(17.63)***	(-14.61)***	(11.63)***	(5.08)***	(1.50)	(-1.85)*	(-1.02)	(0.42)	(-0.04)	(3.11)***	(-0.78)	(0.98)

Table 5: Momentum Returns Over Long Run: Loser and Its Matched Control Portfolio

This table shows returns of loser portfolio and its corresponding control sample in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. For the matching, we find a stock with no momentum – from median portfolios 5 and 6 – with the closest squared distance based on price and size for each loser stock at initial month 0, as long as the match's price and size are within -/+ 10% of those of the loser. Panel A presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. Return t-stats are correlation and heteroscedasticity-consistent.

	Price	Market Value	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		($ Millions)	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
Panel A. Rebalanced Portfolio Returns												
1 unmatched (55%)	8.61	174.30	-39.72%	6.69%	8.55%	22.43%	21.22%	18.63%	18.21%	15.73%	96.47%	124.65%
1 matched (45%)	12.99	159.19	-36.15%	2.39%	5.44%	18.29%	20.25%	17.91%	18.51%	7.84%	88.05%	99.14%
5&6 matched	12.98	158.30	3.18%	8.72%	9.08%	18.59%	18.49%	16.67%	17.21%	18.38%	87.43%	120.45%
5&6 unmatched	37.48	1495.97	3.41%	7.44%	7.72%	15.84%	16.18%	15.41%	15.34%	15.62%	75.86%	102.34%
Matched Diff (1-5&6)	0.01	0.88	-39.34%	-6.31%	-3.64%	-0.30%	1.69%	1.24%	1.32%	-10.54%	0.46%	-21.46%
(t)	(2.13)**	(6.82)***	(-12.01)***	(-4.53)***	(-4.00)***	(-0.35)	(-0.83)	(-0.62)	(-0.98)	(-3.53)***	(-0.09)	(-1.74)*
Panel B. Buy-and-Hold Portfolio Returns												
1 unmatched (55%)	8.61	174.30	-39.72%	3.57%	5.99%	16.30%	14.68%	13.70%	13.29%	9.85%	65.65%	80.38%
1 matched (45%)	12.99	159.19	-36.15%	1.23%	5.18%	17.60%	17.40%	15.59%	15.76%	6.55%	77.14%	87.73%
5&6 matched	12.98	158.30	3.18%	8.46%	8.84%	17.14%	16.51%	14.58%	14.99%	17.87%	76.83%	107.20%
5&6 unmatched	37.48	1495.97	3.41%	7.35%	7.78%	16.06%	15.89%	14.88%	14.61%	15.64%	74.56%	101.30%
Matched Diff (1-5&6)	0.01	0.88	-39.34%	-7.23%	-3.66%	0.46%	0.89%	1.02%	0.77%	-11.32%	0.31%	-19.47%
(t)	(2.13)**	(6.82)***	(-12.01)***	(-4.07)***	(-2.63)***	(0.23)	(-0.43)	(-0.50)	(-0.69)	(-3.02)***	(-1.17)	(-1.79)*

Table 6: Momentum Returns Over Long Run: Winner and Its Matched Control Portfolio

This table shows returns of winner portfolio and its corresponding control sample in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. For the matching, we find a stock with no momentum – from median portfolios 5 and 6 – with the closest squared distance based on price and size for each winner stock at initial month 0, as long as the match's price and size are within -/+ 10% of those of the winner. Panel A presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. Return t-stats are correlation and heteroscedasticity-consistent.

	Price	Market Value	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		($ Millions)	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
Panel A. Rebalanced Portfolio Returns												
5&6 unmatched	37.21	1635.43	3.34%	7.62%	7.91%	16.23%	16.49%	15.38%	15.60%	15.98%	77.29%	104.59%
5&6 matched	21.89	358.10	3.42%	7.87%	8.15%	16.68%	17.17%	16.51%	15.69%	16.50%	80.53%	109.55%
10 matched (64%)	22.01	359.00	75.36%	10.31%	7.22%	12.94%	14.46%	15.91%	14.04%	18.00%	63.86%	92.33%
10 unmatched (36%)	38.57	984.47	81.14%	10.36%	7.41%	13.15%	14.46%	15.98%	12.72%	18.24%	62.09%	91.25%
Matched Diff (10-5&6)	0.12	0.90	71.94%	2.44%	-0.93%	-3.70%	-2.72%	-0.63%	-1.64%	1.51%	-16.67%	-17.20%
(t)	(18.04)***	(4.49)***	(11.06)***	(2.10)**	(-1.32)	(-2.24)**	(-1.99)**	(0.02)	(-0.34)	(0.49)	(-2.06)**	(-2.00)**
Panel B. Buy-and-Hold Portfolio Returns												
5&6 unmatched	37.21	1635.43	3.34%	7.46%	7.88%	16.06%	15.85%	14.49%	14.64%	15.83%	73.93%	100.75%
5&6 matched	21.89	358.10	3.42%	7.81%	8.22%	16.68%	16.57%	15.74%	14.72%	16.55%	77.80%	106.91%
10 matched (64%)	22.01	359.00	75.36%	10.34%	7.68%	14.16%	14.28%	14.55%	13.12%	18.64%	63.14%	92.06%
10 unmatched (36%)	38.57	984.47	81.14%	9.89%	7.22%	12.60%	13.32%	13.45%	10.39%	17.55%	53.32%	79.12%
Matched Diff (10-5&6)	0.12	0.90	71.94%	2.54%	-0.54%	-2.52%	-2.30%	-1.20%	-1.60%	2.09%	-14.67%	-14.85%
(t)	(18.04)***	(4.49)***	(11.06)***	(2.12)**	(-0.97)	(-2.16)**	(-2.18)**	(-0.60)	(-1.06)	(0.58)	(-2.36)**	(-2.12)**

Table 7: Delisting Characteristics of Momentum Portfolios

This table shows when stocks delist from each momentum portfolio, the reason for their delisting, the frequency and the monthly return associated with that specific delisting reason. The delisting code is based on CRSP's identification and "Dropped" means delisting due to bad performance (e.g., bankruptcy). Missing delisting codes are excluded. Momentum portfolios are formed by ranking stocks based on their past 6-month returns and grouping them into decile portfolios. Decile 1 is the loser portfolio and decile 10 is the winner portfolio. The ranking is repeated each month and the sample period is Jun 1951 – Dec 2016.

Port	Delisting Code	%	Delisting Month Return	Port	Delisting Code	%	Delisting Month Return
1	Mergers	29%	5.05%	6	Mergers	64%	3.29%
	Exchanges	2%	-2.04%		Exchanges	4%	2.43%
	Liquidations	2%	6.63%		Liquidations	4%	10.37%
	Dropped	56%	-34.54%		Dropped	22%	-26.78%
2	Mergers	47%	3.98%	7	Mergers	65%	3.11%
	Exchanges	3%	0.76%		Exchanges	4%	1.90%
	Liquidations	3%	8.81%		Liquidations	4%	8.93%
	Dropped	39%	-30.18%		Dropped	21%	-28.11%
3	Mergers	55%	3.45%	8	Mergers	68%	3.33%
	Exchanges	3%	-0.21%		Exchanges	4%	2.23%
	Liquidations	3%	10.69%		Liquidations	4%	10.40%
	Dropped	31%	-29.31%		Dropped	20%	-26.93%
4	Mergers	59%	3.42%	9	Mergers	67%	3.44%
	Exchanges	4%	0.99%		Exchanges	4%	1.90%
	Liquidations	4%	8.67%		Liquidations	4%	9.38%
	Dropped	27%	-26.93%		Dropped	20%	-27.05%
5	Mergers	63%	3.29%	10	Mergers	60%	3.72%
	Exchanges	4%	1.49%		Exchanges	4%	2.31%
	Liquidations	4%	11.88%		Liquidations	4%	13.86%
	Dropped	24%	-26.38%		Dropped	26%	-29.55%

Table 8: Momentum Returns Over Long Run: Rebalanced Portfolio Returns with Surviving Sample Only

This table shows returns of momentum portfolios in each year after the formation for up to five years with the surviving sample, i.e., we require each stock to exist for the entire post formation of five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Rebalanced portfolio returns, where each stock's return is averaged then compounded over time are shown. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-36.29%	11.26%	13.51%	32.06%	29.04%	23.42%	20.55%	26.70%	139.87%	201.19%
2	-20.34%	8.10%	10.17%	23.38%	23.08%	19.35%	18.73%	18.92%	107.21%	143.49%
3	-11.66%	7.85%	8.92%	20.06%	20.37%	17.18%	17.63%	17.18%	94.00%	124.91%
4	-5.13%	7.93%	8.46%	18.20%	18.46%	16.47%	16.78%	16.84%	86.21%	115.78%
5	0.57%	7.94%	8.31%	17.29%	17.44%	16.01%	15.91%	16.74%	81.44%	110.27%
6	6.17%	8.15%	8.39%	16.86%	16.85%	15.76%	15.50%	17.05%	78.52%	107.80%
7	12.33%	8.49%	8.33%	16.95%	16.73%	15.95%	15.18%	17.35%	77.84%	107.67%
8	20.09%	9.08%	8.54%	16.72%	16.55%	16.17%	14.82%	18.17%	76.35%	107.34%
9	32.19%	9.97%	8.50%	16.59%	16.79%	16.77%	14.38%	19.04%	75.63%	108.03%
10	75.46%	12.30%	8.81%	16.07%	17.00%	17.66%	14.30%	21.88%	73.71%	110.04%
Diff (10-1)	111.76%	1.04%	-4.70%	-15.99%	-12.04%	-5.75%	-6.25%	-4.82%	-66.16%	-91.15%
(t)	(6.65)***	(-0.24)	(-3.08)***	(-3.08)***	(-2.77)***	(-2.16)**	(-2.46)**	(-1.60)	(-2.06)**	(-1.87)*
Diff (1-6)	-42.46%	3.11%	5.12%	15.21%	12.19%	7.66%	5.05%	9.64%	61.35%	93.39%
(t)	(-6.82)***	(2.06)**	(3.11)***	(2.80)***	(2.53)**	(2.29)**	(1.92)*	(2.21)**	(1.96)*	(1.80)*
Diff (10-6)	69.30%	4.15%	0.42%	-0.78%	0.16%	1.90%	-1.20%	4.82%	-4.81%	2.24%
(t)	(6.40)***	(3.01)***	(0.39)	(-0.39)	(-0.04)	(1.21)	(-0.02)	(1.96)**	(-0.77)	(0.78)

Table 9: Momentum Returns Over Long Run: Buy-and-Hold Portfolio Returns with Surviving Sample Only

This table shows returns of momentum portfolios in each year after the formation for up to five years with the surviving sample, i.e., we require each stock to exist for the entire post formation of five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time are shown. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-36.29%	9.15%	11.17%	24.45%	19.26%	15.93%	14.24%	21.66%	86.24%	122.09%
2	-20.34%	7.17%	9.33%	20.30%	17.79%	15.05%	14.24%	17.05%	79.35%	107.45%
3	-11.66%	7.28%	8.48%	18.15%	17.21%	14.08%	14.57%	16.18%	76.49%	103.06%
4	-5.13%	7.63%	8.23%	17.06%	16.09%	14.40%	14.69%	16.35%	74.56%	101.82%
5	0.57%	7.72%	8.13%	16.35%	15.72%	14.18%	14.21%	16.37%	72.46%	99.59%
6	6.17%	8.04%	8.31%	16.17%	15.39%	13.81%	13.97%	16.90%	70.47%	98.49%
7	12.33%	8.41%	8.22%	16.45%	15.46%	14.33%	13.75%	17.18%	71.08%	99.72%
8	20.09%	8.98%	8.54%	16.28%	15.27%	14.23%	13.31%	18.11%	69.09%	98.68%
9	32.19%	9.89%	8.51%	16.24%	15.30%	14.27%	12.90%	19.01%	67.54%	98.10%
10	75.46%	12.11%	8.85%	15.36%	14.57%	14.06%	11.91%	21.80%	61.26%	94.26%
Diff (10-1)	111.76%	2.96%	-2.32%	-9.09%	-4.69%	-1.87%	-2.33%	0.14%	-24.98%	-27.83%
(t)	(6.65)***	(0.92)	(-2.25)**	(-2.81)***	(-1.84)*	(-0.59)	(-0.28)	(-0.67)	(-2.04)**	(-1.91)*
Diff (1-6)	-42.46%	1.11%	2.86%	8.28%	3.87%	2.11%	0.27%	4.76%	15.77%	23.59%
(Paired t)	(-6.82)***	(1.16)	(2.46)**	(2.33)**	(1.15)	(0.67)	(-0.29)	(1.60)	(1.44)	(1.51)
Diff (10-6)	69.30%	4.07%	0.54%	-0.81%	-0.82%	0.25%	-2.05%	4.90%	-9.21%	-4.23%
(t)	(6.40)***	(2.96)***	(0.41)	(-0.50)	(-0.89)	(0.25)	(-0.43)	(1.85)*	(-1.71)*	(-1.01)

Table 10: Momentum Returns Over Long Run: Price Terciles

This table shows returns of price sub-portfolios, along with the difference between the highest tercile and lowest tercile, within momentum portfolios 1, 2, 6, 9 and 10 in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns (losers) and decile 10 has stocks with the highest returns (winners). The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Panel A presents the buy-and-hold portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents rebalanced portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

Panel A. Buy-and-Hold Portfolio Returns

	Price	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	3.04	-42.10%	5.34%	5.69%	12.88%	9.91%	9.48%	9.04%	11.51%	48.19%	63.56%
	7.60	-37.76%	1.42%	5.37%	14.80%	14.16%	11.90%	10.54%	6.93%	58.84%	70.50%
	21.01	-34.67%	0.71%	4.15%	15.37%	14.26%	12.43%	11.64%	5.01%	61.40%	68.19%
Diff	17.97	7.43%	-4.63%	-1.54%	2.50%	4.35%	2.96%	2.60%	-6.49%	13.21%	4.62%
(t)	(34.95)***	(6.48)***	(-2.74)***	(-1.03)	(2.04)**	(2.72)***	(2.06)**	(2.14)**	(-2.06)**	(1.63)	(1.07)
2	4.64	-20.83%	6.54%	8.55%	16.04%	13.60%	12.06%	10.01%	15.44%	60.58%	83.54%
	11.91	-20.47%	4.14%	6.77%	16.20%	15.02%	13.13%	11.98%	11.07%	66.88%	84.58%
	31.31	-20.00%	3.75%	5.42%	14.72%	14.15%	12.23%	11.85%	9.37%	61.47%	75.06%
Diff	26.66	0.83%	-2.79%	-3.13%	-1.31%	0.55%	0.17%	1.84%	-6.07%	0.89%	-8.48%
(t)	(36.76)***	(6.28)***	(-1.99)**	(-2.25)**	(0.03)	(1.35)	(0.97)	(2.18)**	(-2.04)**	(0.81)	(0.06)
6	8.29	6.14%	8.73%	9.23%	16.33%	14.30%	11.99%	11.12%	18.66%	63.77%	93.44%
	20.74	6.16%	7.71%	7.73%	14.89%	14.19%	12.83%	12.12%	15.96%	64.85%	91.18%
	70.18	6.20%	6.65%	6.59%	13.70%	13.25%	12.01%	11.57%	13.59%	59.11%	80.22%
Diff	61.89	0.07%	-2.09%	-2.64%	-2.63%	-1.05%	0.02%	0.45%	-5.07%	-4.66%	-13.22%
(t)	(14.54)***	(3.79)***	(-1.47)	(-2.15)**	(-0.82)	(-0.06)	(0.63)	(0.93)	(-1.70)*	(-0.01)	(-0.49)
9	8.65	32.37%	9.98%	8.60%	15.74%	13.78%	11.75%	10.29%	19.19%	60.15%	89.31%
	21.80	32.19%	8.89%	7.62%	14.64%	13.76%	12.53%	11.10%	17.04%	60.76%	87.82%
	62.19	32.11%	8.15%	7.16%	13.17%	12.22%	11.64%	10.03%	15.76%	53.28%	77.37%
Diff	53.54	-0.26%	-1.83%	-1.44%	-2.57%	-1.56%	-0.11%	-0.26%	-3.44%	-6.87%	-11.94%
(t)	(20.14)***	(-3.44)***	(-1.35)	(-1.27)	(-0.81)	(-0.32)	(0.42)	(0.34)	(-1.25)	(-0.18)	(-0.39)
10	7.45	83.66%	9.59%	6.75%	12.02%	11.09%	10.49%	8.34%	16.78%	45.76%	68.31%
	19.11	76.46%	9.97%	7.25%	12.60%	12.56%	11.06%	10.37%	17.74%	52.37%	78.40%
	57.40	71.64%	10.20%	6.88%	11.69%	11.38%	11.61%	8.86%	17.66%	47.28%	72.32%
Diff	49.95	-12.01%	0.62%	0.12%	-0.33%	0.29%	1.12%	0.52%	0.88%	1.52%	4.01%
(t)	(15.45)***	(-4.86)***	(0.48)	(0.31)	(0.32)	(0.82)	(1.10)	(0.99)	(0.50)	(0.61)	(0.64)

Panel B. Rebalanced Portfolio Returns

	Price	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	3.04	-42.10%	10.72%	11.93%	26.65%	21.71%	20.27%	18.52%	24.32%	109.89%	157.26%
	7.60	-37.76%	3.38%	7.33%	21.27%	22.35%	18.96%	19.31%	10.72%	95.81%	112.83%
	21.01	-34.67%	1.24%	3.86%	16.11%	18.30%	16.61%	17.39%	5.14%	78.30%	83.63%
Diff	17.97	7.43%	-9.48%	-8.07%	-10.54%	-3.41%	-3.66%	-1.12%	-19.18%	-31.59%	-73.63%
(t)	(34.95)***	(6.48)***	(-3.73)***	(-3.52)***	(-2.59)***	(-0.61)	(-0.81)	(0.10)	(-2.99)***	(-1.18)	(-1.62)
2	4.64	-20.83%	8.77%	11.50%	23.55%	22.55%	19.91%	19.19%	21.08%	106.97%	146.74%
	11.91	-20.47%	4.54%	6.88%	18.32%	19.54%	17.75%	18.40%	11.47%	90.06%	109.00%
	31.31	-20.00%	4.02%	5.27%	14.96%	16.40%	14.78%	16.21%	9.44%	72.76%	86.40%
Diff	26.66	0.83%	-4.75%	-6.23%	-8.59%	-6.15%	-5.13%	-2.98%	-11.64%	-34.21%	-60.34%
(t)	(36.76)***	(6.28)***	(-3.01)***	(-3.31)***	(-2.24)**	(-2.14)**	(-1.74)*	(-1.10)	(-2.80)***	(-1.79)*	(-1.88)*
6	8.29	6.14%	9.08%	9.79%	19.30%	19.03%	17.46%	17.28%	19.60%	90.90%	126.74%
	20.74	6.16%	7.83%	7.86%	15.79%	16.06%	15.99%	15.86%	16.18%	78.36%	107.01%
	70.18	6.20%	6.75%	6.76%	14.33%	14.75%	13.98%	13.93%	13.86%	67.11%	89.54%
Diff	61.89	0.07%	-2.33%	-3.03%	-4.98%	-4.28%	-3.47%	-3.35%	-5.74%	-23.80%	-37.20%
(t)	(14.54)***	(3.79)***	(-1.64)	(-2.18)**	(-1.49)	(-1.39)	(-1.45)	(-1.57)	(-1.76)*	(-1.34)	(-1.36)
9	8.65	32.37%	10.47%	9.33%	18.38%	18.39%	18.25%	16.36%	20.52%	86.64%	123.60%
	21.80	32.19%	9.00%	7.68%	15.22%	15.97%	16.61%	14.50%	17.16%	73.85%	103.46%
	62.19	32.11%	8.28%	7.28%	13.58%	14.01%	14.46%	12.45%	15.99%	61.98%	88.19%
Diff	53.54	-0.26%	-2.19%	-2.05%	-4.80%	-4.38%	-3.79%	-3.90%	-4.53%	-24.65%	-35.42%
(t)	(20.14)***	(-3.44)***	(-1.55)	(-1.48)	(-1.49)	(-1.59)	(-1.42)	(-1.74)*	(-1.42)	(-1.34)	(-1.32)
10	7.45	83.66%	10.59%	7.85%	14.93%	15.76%	17.28%	15.17%	19.03%	72.19%	102.80%
	19.11	76.46%	9.99%	7.06%	12.66%	14.63%	16.22%	14.25%	17.38%	64.90%	92.88%
	57.40	71.64%	10.50%	6.94%	11.95%	13.38%	14.74%	11.89%	17.92%	55.89%	83.55%
Diff	49.95	-12.01%	-0.10%	-0.92%	-2.99%	-2.37%	-2.54%	-3.28%	-1.11%	-16.30%	-19.25%
(t)	(15.45)***	(-4.86)***	(-0.11)	(-0.76)	(-1.02)	(-0.61)	(-0.73)	(-1.65)*	(-0.38)	(-0.93)	(-0.87)

Table 11: Momentum Returns Over Long Run: Idiosyncratic Volatility Terciles

This table shows returns of idiosyncratic volatility (IVOL) sub-portfolios, along with the difference between the highest tercile and lowest tercile, within momentum portfolios 1, 2, 6, 9 and 10 in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns (losers) and decile 10 has stocks with the highest returns (winners). IVOL is the standard deviation of the residual from the FF-4 factor model. It is estimated using daily data over the six-month pre-formation period [-12, -7] with a minimum requirement of three-month data. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Panel A presents the buy-and-hold portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents rebalanced portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

Panel A. Buy-and-Hold Portfolio Returns

	IVOL	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	0.022	-35.83%	2.17%	4.95%	16.23%	14.50%	13.25%	11.83%	7.48%	65.24%	77.40%
	0.035	-38.06%	2.21%	5.32%	15.48%	13.70%	12.28%	10.50%	7.96%	59.79%	72.17%
	0.062	-40.41%	3.29%	4.83%	11.32%	10.35%	8.51%	7.89%	8.14%	42.87%	53.37%
Diff	0.04	-4.58%	1.13%	-0.14%	-4.92%	-4.14%	-4.75%	-3.94%	0.66%	-22.40%	-24.06%
(t)	(56.78)***	(-6.64)***	(0.99)	(-0.15)	(-2.70)***	(-2.52)**	(-3.02)***	(-3.07)***	(0.32)	(-2.10)**	(-1.83)*
2	0.017	-20.03%	4.58%	6.25%	15.22%	14.08%	12.71%	12.12%	11.06%	64.51%	81.72%
	0.028	-20.48%	4.72%	7.21%	16.53%	15.37%	12.96%	11.60%	12.33%	66.37%	85.68%
	0.050	-20.77%	5.37%	7.35%	15.53%	13.45%	11.93%	10.09%	12.83%	58.57%	77.06%
Diff	0.03	-0.74%	0.76%	1.08%	0.34%	-0.62%	-0.83%	-2.07%	1.74%	-6.07%	-4.86%
(t)	(57.47)***	(-6.36)***	(0.43)	(0.83)	(-0.17)	(-0.96)	(-1.34)	(-2.12)**	(0.50)	(-1.17)	(-0.84)
6	0.012	6.17%	7.17%	7.15%	14.00%	13.53%	12.27%	11.90%	14.86%	61.91%	86.00%
	0.020	6.17%	7.73%	7.82%	15.26%	14.40%	13.06%	12.09%	16.02%	65.45%	91.69%
	0.038	6.16%	8.29%	8.63%	15.95%	13.92%	11.65%	10.90%	17.48%	60.97%	87.88%
Diff	0.03	-0.01%	1.13%	1.48%	1.96%	0.38%	-0.61%	-1.01%	2.62%	-0.94%	1.87%
(t)	(61.34)***	(-1.07)	(0.67)	(1.19)	(0.54)	(-0.34)	(-0.83)	(-1.13)	(0.85)	(-0.51)	(-0.23)
9	0.014	31.70%	8.57%	7.44%	14.08%	13.13%	12.27%	10.41%	16.56%	58.03%	84.46%
	0.023	32.34%	9.34%	8.03%	14.82%	13.77%	12.52%	10.97%	17.94%	60.29%	88.60%
	0.042	32.61%	9.28%	7.98%	15.03%	13.35%	11.40%	9.84%	17.72%	56.57%	82.22%
Diff	0.03	0.92%	0.70%	0.54%	0.96%	0.22%	-0.88%	-0.57%	1.15%	-1.48%	-2.28%
(t)	(55.73)***	(5.68)***	(0.32)	(0.36)	(0.22)	(-0.22)	(-0.71)	(-0.52)	(0.25)	(-0.52)	(-0.51)
10	0.018	63.49%	10.38%	7.24%	12.78%	12.28%	12.04%	9.56%	18.27%	52.55%	79.92%
	0.030	74.67%	10.65%	7.46%	12.82%	12.34%	11.40%	9.64%	18.79%	50.97%	77.87%
	0.054	92.87%	8.97%	6.36%	11.05%	10.88%	10.03%	8.23%	15.58%	42.71%	63.13%
Diff	0.04	29.38%	-1.42%	-0.88%	-1.73%	-1.41%	-2.02%	-1.31%	-2.69%	-9.85%	-16.80%
(t)	(51.41)***	(6.16)***	(-1.07)	(-0.74)	(-1.00)	(-1.44)	(-2.01)**	(-0.59)	(-1.09)	(-1.46)	(-1.48)

Panel B. Rebalanced Portfolio Returns

	IVOL	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	0.022	-35.83%	2.97%	5.46%	18.68%	18.95%	17.44%	17.98%	8.61%	86.62%	99.68%
	0.035	-38.06%	4.02%	7.03%	21.29%	21.88%	19.02%	19.16%	11.40%	94.96%	113.70%
	0.062	-40.41%	7.94%	9.72%	21.95%	21.36%	18.70%	17.57%	18.14%	96.41%	128.58%
Diff	0.04	-4.58%	4.97%	4.26%	3.27%	2.40%	1.26%	-0.41%	9.53%	9.79%	28.90%
(t)	(56.78)***	(-6.64)***	(2.81)***	(2.29)**	(1.25)	(1.19)	(0.37)	(-0.43)	(2.21)**	(0.54)	(1.09)
2	0.017	-20.03%	4.95%	6.27%	16.05%	16.46%	15.66%	16.82%	11.39%	78.51%	96.96%
	0.028	-20.48%	5.20%	7.44%	19.18%	20.13%	17.28%	18.07%	12.93%	89.93%	111.67%
	0.050	-20.77%	7.36%	9.85%	21.32%	21.83%	19.31%	18.59%	17.65%	98.79%	129.34%
Diff	0.03	-0.74%	2.41%	3.58%	5.26%	5.37%	3.65%	1.78%	6.26%	20.28%	32.38%
(t)	(57.47)***	(-6.36)***	(1.57)	(2.25)**	(1.62)	(1.62)	(1.26)	(0.70)	(1.77)*	(1.24)	(1.34)
6	0.012	6.17%	7.31%	7.45%	14.84%	14.85%	14.26%	14.36%	15.31%	70.91%	97.00%
	0.020	6.17%	7.87%	7.97%	16.12%	16.54%	15.92%	15.58%	16.27%	78.19%	106.64%
	0.038	6.16%	8.63%	9.12%	18.65%	18.34%	17.29%	17.10%	18.31%	86.23%	118.86%
Diff	0.03	-0.01%	1.32%	1.66%	3.81%	3.49%	3.03%	2.74%	2.99%	15.32%	21.86%
(t)	(61.34)***	(-1.07)	(0.81)	(1.21)	(1.08)	(1.02)	(1.15)	(1.15)	(0.92)	(0.87)	(0.87)
9	0.014	31.70%	8.78%	7.82%	15.00%	14.92%	15.12%	12.97%	17.16%	68.38%	97.76%
	0.023	32.34%	9.45%	8.08%	15.62%	15.98%	16.71%	14.55%	18.03%	73.98%	105.12%
	0.042	32.61%	9.76%	8.55%	16.69%	17.54%	17.55%	15.67%	18.82%	79.07%	111.13%
Diff	0.03	0.92%	0.98%	0.72%	1.69%	2.62%	2.43%	2.70%	1.66%	10.69%	13.37%
(t)	(55.73)***	(5.68)***	(0.50)	(0.39)	(0.50)	(0.93)	(0.92)	(1.29)	(0.37)	(0.73)	(0.63)
10	0.018	63.49%	10.83%	7.79%	14.13%	14.75%	15.90%	12.95%	19.26%	66.07%	98.18%
	0.030	74.67%	10.82%	7.37%	13.32%	14.67%	16.44%	14.01%	18.70%	64.66%	94.31%
	0.054	92.87%	9.74%	7.14%	12.44%	14.59%	16.13%	14.18%	17.16%	62.17%	88.56%
Diff	0.04	29.38%	-1.09%	-0.65%	-1.69%	-0.16%	0.23%	1.23%	-2.10%	-3.90%	-9.62%
(t)	(51.41)***	(6.16)***	(-0.74)	(-0.40)	(-0.54)	(-0.19)	(-0.04)	(0.91)	(-0.70)	(-0.46)	(-0.68)

Table 12: Momentum Returns Over Long Run: Amihud Terciles

This table shows returns of sub-portfolios based on the Amihud (2002) measure, along with the difference between the highest tercile and lowest tercile, within momentum portfolios 1, 2, 6, 9 and 10 in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns (losers) and decile 10 has stocks with the highest returns (winners). Amihud measures the price impact of one-million dollar of trading volume, i.e., $Average(\frac{|r_t|}{Volume_t}) * 10^6$. It is estimated using daily data over the six-month pre-formation period [-12, -7] with a minimum requirement of three-month data. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. Panel A presents the buy-and-hold portfolio returns, where each stock's return is averaged then compounded over time. Panel B presents rebalanced portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

Panel A. Buy-and-Hold Portfolio Returns

	Amihud	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	2.41	-37.25%	0.97%	4.44%	14.15%	13.09%	12.19%	11.44%	5.55%	56.85%	64.49%
	9.76	-37.73%	2.59%	4.76%	14.75%	13.96%	11.86%	10.62%	7.47%	58.99%	68.69%
	48.44	-37.60%	3.78%	6.44%	15.49%	13.38%	10.85%	9.85%	10.35%	57.71%	73.00%
Diff	46.03	-0.35%	2.78%	2.01%	1.37%	0.29%	-1.35%	-1.63%	4.77%	0.83%	8.47%
(t)	(31.70)***	(-0.99)	(2.41)**	(1.28)	(0.17)	(0.25)	(-0.74)	(-0.79)	(1.72)*	(0.24)	(0.68)
2	2.02	-20.35%	3.95%	5.93%	14.10%	14.23%	12.16%	11.89%	10.03%	59.39%	73.36%
	8.44	-20.44%	4.61%	7.13%	15.86%	14.24%	12.94%	11.34%	11.84%	63.94%	81.93%
	45.72	-20.40%	6.15%	8.02%	17.33%	14.74%	13.15%	11.00%	14.55%	66.42%	89.57%
Diff	43.70	-0.05%	2.19%	2.09%	3.25%	0.51%	0.97%	-0.94%	4.50%	6.93%	16.06%
(t)	(33.52)***	(-1.24)	(2.15)**	(2.04)**	(1.53)	(0.10)	(0.62)	(-0.19)	(1.86)*	(1.12)	(1.39)
6	1.62	6.17%	6.47%	6.76%	13.12%	13.13%	12.30%	12.02%	13.48%	58.45%	78.83%
	7.08	6.17%	7.52%	7.62%	14.83%	13.76%	12.28%	11.99%	15.52%	62.59%	87.01%
	39.45	6.16%	9.03%	9.08%	16.75%	14.50%	12.51%	11.13%	18.95%	65.42%	97.06%
Diff	37.82	-0.00%	2.56%	2.32%	3.62%	1.37%	0.21%	-0.89%	5.46%	6.92%	18.17%
(t)	(52.84)***	(-0.36)	(3.26)***	(2.86)***	(1.87)*	(0.83)	(0.20)	(-0.79)	(2.58)***	(0.91)	(1.40)
9	1.92	31.99%	7.52%	6.91%	13.32%	12.35%	12.03%	10.44%	14.71%	54.09%	76.27%
	8.21	32.24%	9.11%	7.73%	14.44%	12.97%	12.19%	10.60%	17.25%	57.40%	83.47%
	41.47	32.32%	10.40%	8.87%	16.05%	14.50%	12.30%	10.54%	20.04%	62.37%	94.15%
Diff	39.55	0.33%	2.87%	1.96%	2.74%	2.16%	0.26%	0.09%	5.32%	8.30%	17.88%
(t)	(46.56)***	(4.29)***	(3.67)***	(2.42)**	(0.96)	(0.87)	(-0.01)	(0.19)	(2.74)***	(0.88)	(1.47)
10	2.75	68.55%	9.24%	6.84%	11.40%	11.00%	11.17%	9.51%	16.48%	46.57%	69.31%
	11.48	75.55%	10.26%	7.22%	12.24%	11.91%	11.49%	8.99%	17.97%	48.12%	73.07%
	51.57	80.40%	10.59%	7.61%	13.54%	13.01%	11.93%	9.14%	18.83%	53.10%	80.77%
Diff	48.82	11.85%	1.36%	0.76%	2.15%	2.01%	0.76%	-0.35%	2.34%	6.64%	11.57%
(t)	(41.92)***	(6.10)***	(1.80)*	(1.08)	(0.78)	(0.08)	(0.19)	(-0.26)	(1.38)	(0.49)	(0.88)

Panel B. Rebalanced Portfolio Returns

	Amihud	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
		[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	2.41	-37.25%	1.96%	5.26%	17.27%	18.12%	16.32%	17.84%	7.07%	75.52%	83.20%
	9.76	-37.73%	4.80%	6.68%	19.80%	20.35%	18.29%	17.06%	11.65%	86.79%	104.40%
	48.44	-37.60%	6.71%	9.22%	22.71%	22.43%	19.83%	19.01%	16.25%	104.53%	133.65%
Diff	46.03	-0.35%	4.75%	3.95%	5.44%	4.31%	3.51%	1.16%	9.18%	29.01%	50.46%
(t)	(31.70)***	(-0.99)	(3.61)***	(2.81)***	(2.28)**	(1.67)*	(1.55)	(0.70)	(2.92)***	(1.91)*	(1.84)*
2	2.02	-20.35%	4.26%	5.91%	15.43%	17.38%	15.03%	16.41%	10.18%	72.57%	86.21%
	8.44	-20.44%	5.40%	7.66%	18.41%	18.96%	17.62%	17.48%	13.13%	86.48%	108.16%
	45.72	-20.40%	7.51%	9.64%	21.47%	20.82%	19.59%	18.14%	17.67%	101.22%	133.82%
Diff	43.70	-0.05%	3.25%	3.74%	6.04%	3.44%	4.56%	1.74%	7.49%	28.65%	47.60%
(t)	(33.52)***	(-1.24)	(3.50)***	(3.75)***	(2.70)***	(1.32)	(2.05)**	(1.75)*	(3.13)***	(1.99)**	(1.95)*
6	1.62	6.17%	6.55%	6.87%	13.77%	14.65%	14.42%	14.35%	13.61%	65.97%	87.43%
	7.08	6.17%	7.60%	7.80%	15.91%	16.22%	15.57%	15.87%	15.72%	76.37%	102.82%
	39.45	6.16%	9.37%	9.65%	19.04%	17.83%	16.84%	15.90%	19.89%	87.35%	124.85%
Diff	37.82	-0.00%	2.82%	2.78%	5.27%	3.19%	2.42%	1.55%	6.28%	21.39%	37.42%
(t)	(52.84)***	(-0.36)	(3.46)***	(3.45)***	(2.40)**	(1.66)*	(1.49)	(1.27)	(2.87)***	(1.68)*	(1.73)*
9	1.92	31.99%	7.60%	6.93%	13.41%	14.02%	14.74%	12.70%	14.74%	61.36%	85.01%
	8.21	32.24%	9.10%	7.97%	15.16%	15.78%	16.48%	14.41%	17.45%	71.58%	100.86%
	41.47	32.32%	10.93%	9.49%	18.46%	18.19%	17.80%	15.54%	21.27%	85.60%	124.00%
Diff	39.55	0.33%	3.33%	2.56%	5.05%	4.16%	3.06%	2.84%	6.53%	24.25%	38.99%
(t)	(46.56)***	(4.29)***	(3.99)***	(2.86)***	(2.07)**	(1.91)*	(1.53)	(2.02)**	(3.08)***	(1.79)*	(1.83)*
10	2.75	68.55%	9.35%	6.96%	11.47%	13.06%	14.87%	12.52%	16.58%	54.68%	79.69%
	11.48	75.55%	10.53%	7.41%	12.82%	14.54%	16.51%	13.36%	18.30%	62.18%	90.90%
	51.57	80.40%	11.42%	8.31%	15.58%	16.87%	17.76%	14.91%	20.46%	75.15%	109.79%
Diff	48.82	11.85%	2.07%	1.34%	4.11%	3.81%	2.89%	2.40%	3.88%	20.48%	30.11%
(t)	(41.92)***	(6.10)***	(2.58)***	(1.62)	(1.54)	(1.53)	(1.57)	(1.61)	(2.02)**	(1.81)*	(1.75)*

Table 13: Average Characteristics of Momentum Portfolios in Pre- and Post-Decimalization

This table shows the mean and median (in parentheses) price, market value of equity, and individual return standard deviation for each momentum portfolio in pre- and post-decimalization. Momentum portfolios are formed by ranking stocks based on their past 6-month returns and grouping them into decile portfolios. Decile 1 is the loser portfolio and decile 10 is the winner portfolio. The ranking is repeated each month and each statistics is averaged across the subperiods of Pre- and Post-Decimalization (Jun 1951 – Apr 1997 and Apr 2001 – Dec 2016) and a subperiod of Post-Decimalization (Apr 2001 – Aug 2007). Price and market value of equity are end-of-formation month values. Std is estimated using available non-missing returns over the five-year holding period.

	Price			Market Value ($ Millions)			$\text{Std}_{[1,60]}$		
	Pre-Deci	Post-Deci	Post-Deci I	Pre-Deci	Post-Deci	Post-Deci I	Pre-Deci	Post-Deci	Post-Deci I
	195106 : 199704	200104 : 201612	200104 : 200708	195106 : 199704	200104 : 201612	200104 : 200708	195106 : 199704	200104 : 201612	200104 : 200708
1	13.07	5.79	3.46	79.25	484.91	527.41	17.91%	25.09%	31.19%
	(9.64)	(3.03)	(1.43)	(17.25)	(69.27)	(36.29)	(15.79%)	(21.55%)	(26.96%)
2	18.19	12.13	7.81	163.63	1625.74	1440.84	13.91%	18.52%	23.26%
	(14.02)	(8.06)	(4.06)	(29.47)	(172.19)	(77.40)	(12.36%)	(15.82%)	(20.27%)
3	21.12	44.49	20.66	235.03	2616.92	2389.78	12.22%	15.65%	18.40%
	(16.83)	(11.98)	(7.56)	(38.37)	(255.38)	(124.33)	(10.82%)	(13.19%)	(15.64%)
4	23.26	60.69	41.06	273.57	3591.25	3556.45	11.28%	13.92%	15.48%
	(18.78)	(15.19)	(11.55)	(44.90)	(339.21)	(192.34)	(9.92%)	(11.59%)	(12.61%)
5	24.98	60.75	45.05	328.71	4118.30	4193.96	10.78%	12.72%	12.91%
	(20.56)	(17.57)	(15.14)	(52.69)	(407.78)	(241.94)	(9.43%)	(10.63%)	(10.04%)
6	26.70	59.26	46.65	351.30	4326.19	3458.36	10.47%	12.32%	11.94%
	(21.86)	(19.05)	(16.73)	(58.52)	(471.49)	(248.21)	(9.20%)	(10.20%)	(8.94%)
7	28.00	60.37	70.98	382.66	4213.40	2646.87	10.39%	12.13%	11.45%
	(23.00)	(19.71)	(17.45)	(64.24)	(513.11)	(221.11)	(9.17%)	(10.18%)	(8.70%)
8	28.68	51.22	21.77	384.40	3853.00	1914.07	10.64%	12.38%	11.66%
	(23.53)	(19.75)	(17.21)	(65.83)	(519.12)	(212.29)	(9.44%)	(10.51%)	(9.05%)
9	29.05	34.44	19.55	332.14	3076.43	1202.22	11.24%	13.41%	13.02%
	(23.33)	(18.33)	(15.52)	(61.68)	(476.30)	(185.87)	(10.09%)	(11.61%)	(10.67%)
10	27.22	33.34	14.53	191.00	1471.34	474.27	13.24%	16.16%	16.73%
	(20.98)	(13.51)	(10.15)	(42.49)	(305.72)	(132.03)	(12.08%)	(14.47%)	(14.72%)

Table 14: Momentum Returns Over Long Run: Buy-and-Hold Portfolio Returns in Post-Decimalization

This table shows returns of momentum portfolios in each year after the formation for up to five years in post-decimalization. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Apr 2001 – Dec 2016. This table presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-48.13%	5.86%	5.16%	13.18%	6.57%	7.65%	6.52%	13.50%	35.76%	51.77%
2	-26.15%	5.76%	7.38%	14.57%	8.70%	8.38%	7.36%	13.86%	42.96%	58.89%
3	-15.55%	5.98%	6.59%	14.35%	10.26%	8.49%	8.03%	12.96%	47.28%	63.12%
4	-7.80%	6.31%	5.93%	13.35%	10.30%	8.51%	8.07%	12.51%	46.59%	63.13%
5	-1.22%	6.30%	5.85%	13.18%	10.45%	8.48%	7.64%	12.43%	46.03%	63.12%
6	5.14%	6.39%	5.64%	12.37%	10.84%	8.75%	7.12%	12.28%	44.85%	61.68%
7	12.06%	6.70%	5.58%	12.57%	10.45%	9.17%	7.17%	12.58%	44.60%	61.81%
8	20.89%	6.74%	5.60%	12.76%	10.88%	9.11%	6.32%	12.50%	43.47%	59.99%
9	35.16%	6.90%	5.08%	13.05%	10.82%	9.53%	5.28%	11.94%	42.60%	57.48%
10	92.59%	6.59%	3.45%	12.12%	9.94%	9.16%	4.57%	9.65%	37.75%	47.88%
Diff (10-1)	140.72%	0.73%	-1.70%	-1.06%	3.36%	1.51%	-1.95%	-3.85%	1.99%	-3.89%
(t)	(3.29)***	(0.16)	(-0.46)	(-0.40)	(1.48)	(1.27)	(-0.91)	(-0.36)	(1.01)	(-0.51)
Diff (1-6)	-53.26%	-0.53%	-0.48%	0.81%	-4.27%	-1.10%	-0.60%	1.21%	-9.10%	-9.92%
(t)	(-3.37)***	(-0.10)	(-0.06)	(0.35)	(-1.72)*	(-0.96)	(-0.46)	(0.14)	(-1.37)	(-3.48)***
Diff (10-6)	87.45%	0.19%	-2.19%	-0.26%	-0.90%	0.41%	-2.55%	-2.63%	-7.11%	-13.80%
(t)	(3.18)***	(0.20)	(-1.88)*	(0.06)	(-0.81)	(0.42)	(-1.60)	(-1.10)	(-1.30)	(-1.23)

Table 15: Momentum Returns Over Long Run: Rebalanced Portfolio Returns in Post-Decimalization

This table shows returns of momentum portfolios in each year after the formation for up to five years in post-decimalization. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Apr 2001 – Dec 2016. This table presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-48.13%	8.87%	8.36%	23.95%	13.20%	12.41%	12.22%	20.16%	56.79%	76.30%
2	-26.15%	7.10%	9.28%	21.79%	13.47%	12.26%	13.46%	17.30%	62.73%	81.45%
3	-15.55%	6.82%	7.62%	19.31%	14.00%	11.31%	14.16%	14.65%	65.57%	83.31%
4	-7.80%	6.74%	6.83%	17.29%	13.25%	10.97%	12.23%	13.59%	61.09%	78.65%
5	-1.22%	6.55%	6.55%	16.29%	13.12%	10.63%	11.03%	13.27%	58.08%	76.11%
6	5.14%	6.53%	6.30%	15.40%	13.23%	11.20%	10.07%	12.92%	56.40%	74.10%
7	12.06%	6.80%	6.24%	15.39%	13.78%	11.98%	9.71%	13.23%	57.07%	75.33%
8	20.89%	6.77%	6.27%	15.72%	14.03%	12.02%	9.24%	13.03%	56.20%	73.22%
9	35.16%	7.07%	5.84%	16.62%	14.55%	13.20%	7.87%	12.69%	56.29%	72.10%
10	92.59%	6.90%	4.28%	15.97%	13.82%	13.34%	7.28%	10.42%	50.51%	61.37%
Diff (10-1)	140.72%	-1.97%	-4.07%	-7.98%	0.62%	0.93%	-4.94%	-9.74%	-6.28%	-14.93%
(t)	(3.29)***	(-0.25)	(-0.72)	(-0.98)	(0.34)	(0.33)	(-1.20)	(-0.67)	(-1.28)	(-2.28)**
Diff (1-6)	-53.26%	-2.35%	-2.06%	-8.55%	0.02%	-1.21%	-2.16%	-7.24%	-0.39%	-2.20%
(t)	(-3.37)***	(0.34)	(0.38)	(0.90)	(-0.12)	(0.21)	(0.51)	(0.54)	(0.49)	(-0.29)
Diff (10-6)	87.45%	0.38%	-2.01%	0.57%	0.59%	2.13%	-2.79%	-2.50%	-5.89%	-12.73%
(t)	(3.18)***	(0.26)	(-1.55)	(0.43)	(0.24)	(0.74)	(-1.19)	(-0.82)	(-0.91)	(-0.99)

Table 16: Momentum Returns Over Long Run: Buy-and-Hold Portfolio Returns in Post-Decimalization Before Crisis

This table shows returns of momentum portfolios in each year after the formation for up to five years in post-decimalization but before the financial crisis. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Apr 2001 – Aug 2007. This table presents buy-and-hold portfolio returns, where each stock's return is compounded then averaged over time. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-65.31%	-13.42%	0.78%	53.89%	5.76%	10.07%	5.95%	-14.18%	87.80%	51.77%
2	-38.22%	-10.51%	3.45%	52.99%	11.31%	10.60%	7.77%	-9.24%	100.36%	72.42%
3	-22.17%	-6.60%	3.65%	46.34%	16.93%	15.65%	11.37%	-5.03%	116.84%	100.12%
4	-10.73%	-3.32%	3.27%	40.48%	17.74%	15.39%	11.85%	-1.89%	110.45%	104.90%
5	-1.67%	-0.28%	3.83%	35.66%	18.77%	14.35%	11.40%	2.11%	103.09%	105.74%
6	6.29%	0.57%	4.67%	31.60%	17.65%	14.68%	10.21%	4.17%	94.11%	101.31%
7	14.21%	1.74%	4.77%	33.09%	15.93%	14.94%	9.93%	5.60%	93.55%	103.49%
8	23.65%	1.31%	4.40%	34.14%	16.57%	14.02%	9.16%	4.82%	93.07%	100.35%
9	38.96%	0.28%	4.56%	38.32%	16.51%	16.01%	8.30%	3.96%	100.35%	105.79%
10	104.76%	-1.97%	3.03%	42.81%	14.16%	16.31%	8.58%	-0.73%	101.38%	97.98%
Diff (10-1)	170.07%	11.46%	2.25%	-11.09%	8.40%	6.24%	2.63%	13.45%	13.58%	46.21%
(t)	(1.33)	(1.21)	(0.24)	(-0.96)	(1.03)	(1.02)	(1.21)	(0.79)	(1.00)	(1.00)
Diff (1-6)	-71.59%	-13.99%	-3.89%	22.29%	-11.89%	-4.61%	-4.26%	-18.35%	-6.31%	-49.54%
(t)	(-1.34)	(-1.17)	(-0.32)	(0.99)	(-1.02)	(-1.23)	(-1.04)	(-0.86)	(-1.00)	(-1.00)
Diff (10-6)	98.48%	-2.53%	-1.64%	11.21%	-3.49%	1.63%	-1.63%	-4.90%	7.27%	-3.34%
(t)	(1.33)	(-0.71)	(-0.66)	(0.99)	(-1.01)	(0.75)	(-1.03)	(-1.00)	(1.00)	(-1.00)

Table 17: Momentum Returns Over Long Run: Rebalanced Portfolio Returns in Post-Decimalization Before Crisis

This table shows returns of momentum portfolios in each year after the formation for up to five years in post-decimalization but before the financial crisis. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Apr 2001 – Aug 2007. This table presents the rebalanced portfolio returns, where each stock's return is averaged then compounded over time. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-65.31%	-9.96%	6.20%	110.08%	9.26%	10.12%	9.87%	-5.93%	167.87%	122.96%
2	-38.22%	-8.54%	6.82%	81.43%	16.02%	11.73%	11.40%	-4.28%	153.85%	123.92%
3	-22.17%	-5.88%	4.09%	63.11%	22.16%	16.51%	14.41%	-3.84%	161.73%	141.54%
4	-10.73%	-2.89%	2.74%	51.55%	20.98%	16.68%	15.92%	-2.07%	143.63%	135.10%
5	-1.67%	-0.00%	3.94%	43.58%	22.38%	15.39%	14.77%	2.43%	129.86%	133.07%
6	6.29%	0.84%	4.54%	40.54%	20.75%	15.32%	13.70%	4.24%	120.16%	127.86%
7	14.21%	2.00%	4.95%	40.99%	20.32%	15.98%	11.87%	6.00%	118.01%	129.36%
8	23.65%	1.51%	4.80%	43.00%	19.68%	15.64%	12.07%	5.31%	119.69%	128.34%
9	38.96%	0.71%	5.05%	49.72%	19.98%	16.44%	10.95%	4.55%	128.55%	135.85%
10	104.76%	-1.63%	4.46%	56.88%	16.36%	18.39%	11.90%	0.58%	135.40%	132.71%
Diff (10-1)	170.07%	8.33%	-1.73%	-53.19%	7.10%	8.27%	2.03%	6.51%	-32.47%	9.75%
(t)	(1.33)	(1.01)	(-0.04)	(-1.00)	(0.93)	(1.01)	(0.71)	(0.46)	(-1.00)	(1.00)
Diff (1-6)	-71.59%	-10.80%	1.66%	69.53%	-11.49%	-5.20%	-3.83%	-10.17%	47.71%	-4.90%
(t)	(-1.34)	(-0.99)	(0.02)	(1.00)	(-0.96)	(-1.14)	(-0.96)	(-0.59)	(1.00)	(-1.00)
Diff (10-6)	98.48%	-2.47%	-0.07%	16.34%	-4.39%	3.07%	-1.80%	-3.67%	15.24%	4.85%
(t)	(1.33)	(-0.68)	(-0.07)	(1.00)	(-0.99)	(0.94)	(-0.88)	(-0.99)	(1.00)	(1.00)

Table 18: Momentum Returns Over Long Run: Value-Weighted Portfolio Returns

This table shows returns of momentum portfolios in each year after the formation for up to five years. We form momentum portfolios in the following ways: at the end of each month (month -1), we rank stocks based on their past 6-month return and group them into decile portfolios. Decile 1 has stocks with the lowest past returns and decile 10 has stocks with the highest returns. The ranking is repeated each month and each portfolio return is averaged across the sample period of Jun 1951 – Dec 2016. This table presents value-weighted returns based on beginning of holding period market values. Delisted wealth is assumed to be reinvested in the portfolio. All return t-stats are adjusted for correlation and heteroscedasticity following Jegadeesh and Karceski (2009).

	Formation	Year 1		Year 2	Year 3	Year 4	Year 5	Year 1: Total	Year 2: 5	Post: Total
	[-6, -1]	[1, 6]	[7, 12]	[13, 24]	[25, 36]	[37, 48]	[49, 60]	[1, 12]	[13, 60]	[1, 60]
1	-38.18%	0.70%	4.01%	14.99%	15.98%	14.68%	14.50%	4.73%	68.15%	73.82%
2	-20.44%	3.26%	5.02%	15.21%	15.24%	13.56%	13.73%	8.53%	67.00%	79.07%
3	-11.69%	4.51%	5.48%	13.94%	15.44%	12.37%	13.53%	10.17%	65.03%	80.45%
4	-5.15%	5.20%	5.42%	13.83%	13.63%	12.26%	12.91%	10.88%	61.83%	78.58%
5	0.56%	5.38%	5.86%	13.00%	13.17%	12.38%	12.40%	11.51%	59.95%	78.15%
6	6.17%	5.75%	5.92%	12.72%	12.68%	12.33%	12.72%	11.98%	59.44%	78.52%
7	12.34%	6.06%	6.24%	12.66%	12.48%	12.52%	11.64%	12.69%	57.47%	77.45%
8	20.10%	6.52%	6.71%	12.78%	12.56%	12.31%	11.76%	13.61%	57.52%	79.15%
9	32.22%	6.98%	6.76%	12.83%	12.75%	13.52%	11.03%	14.14%	58.03%	80.93%
10	77.27%	8.09%	7.33%	12.32%	12.71%	14.06%	12.01%	15.86%	58.18%	82.56%
Diff (10-1)	115.45%	7.40%	3.32%	-2.66%	-3.27%	-0.62%	-2.50%	11.12%	-9.97%	8.75%
(t)	(6.65)***	(3.54)***	(1.84)*	(-1.11)	(-1.21)	(0.17)	(-0.51)	(3.17)***	(-0.59)	(1.42)
Diff (1-6)	-44.35%	-5.05%	-1.90%	2.27%	3.30%	2.35%	1.78%	-7.25%	8.71%	-4.71%
(t)	(-6.79)***	(-3.14)***	(-0.95)	(0.98)	(1.03)	(0.87)	(0.89)	(-2.21)**	(0.75)	(-0.52)
Diff (10-6)	71.11%	2.34%	1.42%	-0.39%	0.03%	1.74%	-0.72%	3.87%	-1.25%	4.04%
(t)	(6.42)***	(1.47)	(1.21)	(-0.24)	(-0.11)	(0.97)	(0.24)	(1.59)	(0.25)	(0.81)