

Arbitrage at its Limits:
Hedge Funds and the Technology Bubble

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ABSTRACT: Classical finance theory maintains that rational arbitrageurs would find it optimal to attack price bubbles and thus exert a correcting force on prices. We examine stock holdings of hedge funds during the time of the technology bubble on the NASDAQ. Counter to the classical view, we find that hedge fund portfolios were heavily tilted towards (overpriced) technology stocks. This does not seem to be the result of unawareness of the bubble: At an individual stock level these investments were well timed. On average, hedge funds started to reduce their exposure in the quarter prior to price peaks of individual technology stocks, and their overall stock holdings in the technology segment outperformed characteristics-matched benchmarks. Our findings are consistent with models in which arbitrage is limited, because arbitrageurs face constraints, are unable to temporally coordinate their strategies, and investor sentiment is predictable. Our results also suggest that frictions such as short-sales constraints are not sufficient to explain why the presence of sophisticated investors failed to contain the bubble.

Keywords: Limits of Arbitrage; Bubbles; Behavioral Finance

JEL classification: G12, G14, G23

1.Introduction

Technology stocks on NASDAQ rose to unprecedented levels during the two years leading up to March 2000. Ofek and Richardson (2001) estimate that, at the peak, the entire internet sector, comprising several hundred stocks, was priced as if the *average* future earnings growth rate of these firms would exceed the growth rates experienced by some of the fastest growing firms in the past, and, at the same time, the required rate of return would be *zero percent* for several decades. By almost any standard, such valuation levels are so outrageous that this period appears to be another episode in the history of asset price bubbles.¹

Shiller (2000) argues that the stock price increase was driven by irrational euphoria among individual investors, fed by an emphatic media, which maximized TV-ratings and catered to investor demand for pseudo-news. Of course, only few economists doubt that there are both rational and irrational market participants. However, there are two opposing views about whether rational traders correct the price impact of behavioral traders. The classic efficient market hypothesis (Friedman 1953, Fama 1965) predicts that sophisticated rational traders will undo any mispricing caused by “irrational exuberance”. The literature on limits of arbitrage questions this claim. It argues that various factors such as market timing incentives, noise trader risk, and transactions costs constrain arbitrage.

Our objective in this paper is to empirically characterize the response of “rational arbitrageurs” to the growth of the technology bubble. Specifically, we examine stock holdings of hedge funds during the 1998 to 2000 period. Our choice to look at hedge funds is motivated by the fact that hedge funds are highly sophisticated investors, who should come closest to the ideal of “rational arbitrageurs” in classical finance theory. By observing their trading behavior,

¹ Other interesting anomalous pricing phenomena during this period are documented in Lamont and Thaler (2001), who show that some carved-out subsidiaries were so overpriced relative to the parent firm that the law of one price was violated. Cooper, Dimitrov, and Rau (2001) document that the mere announcement of a name change into “dot.com” was associated with average abnormal returns of 74 percent over a ten-day window.

we are able to examine whether hedge funds were indeed a correcting force during the bubble period, and it also allows us to provide empirical evidence on limits to arbitrage.

Our study is unusual in that we look at hedge fund holdings directly. In general, data on hedge funds is very difficult to obtain, since hedge funds are not regulated by the SEC. However, like other institutional investors, hedge funds with large holdings in U.S. equities do have to report their quarterly equity long positions to the SEC on form 13F. We extract hedge fund holdings from these data, including those of well-known managers such as Soros, Tiger, Tudor, and others. To the best of our knowledge, our paper is the first to use holdings data to analyze the trading activities of hedge funds. To assess the effect of short positions and derivatives, we also look at returns of hedge funds.

Our empirical investigation yields several interesting results. First, our analysis indicates that hedge funds were riding the technology bubble. Over our sample period 1998-2000, hedge fund portfolios were heavily tilted towards technology stocks. The proportion of their overall stock holdings devoted to this segment was overweight compared to the corresponding weight in the market portfolio. They increased their holdings in the bubble segment during the summer of 1999, even though media statements during this time indicate that they may have known that the prices were already too high.² Hedge fund returns data reveals that this exposure on the long side was not offset by short positions or derivatives. This market timing behavior is consistent with the recent theoretical literature on limits of arbitrage. These models show that it can be optimal for rational arbitrageurs to ride a price bubble for a while.

Of course, it is certainly also a logical possibility that hedge funds simply failed to spot the bubble. This concern is underscored by the fact that—with the exception of short-selling

²For example, Stanley Druckenmiller of Soros Fund Management observed already in 1999: “After having made money in the internet pre-January 1999, on the long side, we were too early in calling the bursting of the internet bubble.” (Wall Street Journal, August 10, 1999, C1). Interestingly, as our data shows, this ‘bubble-view’ did not keep Soros Fund Management from pouring several billion dollars into technology stocks during the same quarter.

specialist funds—there are no aggressive reductions in hedge funds’ exposure to the technology segment prior the price peak on NASDAQ in March 2000. However, the technology bubble was not a homogenous event, where all stocks peaked in March 2000. Price peaks for many individual technology stocks occurred sooner as well as later. It turns out that the hedge funds in our sample skillfully anticipated these peaks of individual stocks. On average, they started to cut back their holdings in the quarter prior to these peaks. This cut-back continued afterwards. This timing behavior is much more pronounced for technology stocks than for stocks in other market segments. So it seems that the technology exposure of hedge funds cannot simply be explained by unawareness of the bubble. It also shows that hedge fund managers were able to predict some of the investor sentiment that was arguably behind the wild fluctuations in valuations of technology stocks at that time. In fact, our data show that hedge funds earned substantial excess returns in the technology segment of the NASDAQ. A portfolio that mimics their holdings exhibits abnormal returns in excess of a characteristics-matched benchmark of around 4.5 percent per quarter. What happened is that in 2000 hedge funds still held large investments in technology stocks, but these holdings were concentrated in stocks that did not crash yet.

Overall, our findings cast doubt on the classical view that it is always optimal for rational arbitrageurs to attack a bubble. While the exact implications of our results for the mechanism limiting arbitrage may be open to different interpretations, two points seem clear: First, there is no evidence that hedge funds as a whole exerted a correcting force on prices during the technology bubble. Among the few large hedge funds that did, the manager with the least exposure to technology stocks—Tiger Management—did not survive until the bubble burst. Second, it appears that frictions, such as short-sales constraints, and aversion to arbitrage risk alone are not sufficient to understand the failure of rational arbitrage to contain the bubble. While they may explain the unwillingness of professional investors to short overpriced

technology stocks, they do not explain our finding that hedge funds actually held long positions in these stocks.

Before we proceed, a caveat is in order. While we believe that our results give an interesting account of the differences between the assumed roles of arbitrageurs in finance textbooks, and the trading behavior of some of the most sophisticated players in real-world markets, the size of our data set limits us to analyses that are mainly descriptive. In this respect, we view our work more as a clinical study of arbitrageurs' trading strategies during a bubble episode, than as an attempt to formally test theories. Nevertheless, we add much needed empirical evidence to the predominantly theoretical work on limits of arbitrage.

The rest of our paper is organized as follows. Section 2 summarizes the prior theoretical and empirical literature. Our stock holdings, price and volume data are described in section 3. In section 4 we investigate the weight hedge funds devoted to technology stocks in their portfolios. Section 5 provides results on the timing of their exposure at an individual stock level. Section 6 concludes.

2. Related Literature

Our analysis is related to the theoretical literature on limits to arbitrage. This literature highlights various mechanisms that hinder arbitrageurs' ability to correct mispricing, including coordination problems, noise trader risk and transactions costs.

In Abreu and Brunnermeier (2001), rational arbitrageurs ride a growing bubble and try to time the market. Abreu and Brunnermeier (2002) extend this result for a more general form of mispricing and introduce the notion of synchronization risk. A crucial element of the timing game in both papers is that a single arbitrageur cannot bring the market down on his own and some *coordination* is required. This seems reasonable as the capital of large hedge funds rarely exceeds \$20 billion. Even taking into account their ability to use leverage, this is rather small

compared with a combined market capitalization of all NASDAQ stocks in excess of \$5 trillion in 1999. Nevertheless, a coordinated move by all hedge funds might change investor sentiment and thereby trigger a crash. However, this coordination is difficult in Abreu and Brunnermeier's timing game, because there is a dispersion of opinion about when the stock market will peak. Our finding that hedge funds were riding the bubble, and that they earned excess profits from doing so is consistent with their model.

DeLong, Shleifer, Summers and Waldmann (DSSW) (1990a) show that *noise trader risk* also limits arbitrage. Risk-averse arbitrageurs with short-horizons are reluctant to exploit long-run arbitrage opportunities since they are afraid of the risk that the price could depart even further from the fundamental value due to random noise trader demand. Shleifer and Vishny (1997) provide a compelling argument for why fund managers may have short horizons. If the price departs even further from the fundamental value, they make temporary losses, which might cause clients to withdraw their money. Consistent with this view, Chevalier and Ellison (1997) document that bad performing mutual funds experience fund outflows. One might expect, however, that this is less of a problem for hedge funds. First, they typically feature a small wealthy client base, which may help to reduce information asymmetries. Second, hedge fund contracts with clients commonly contain provisions, which only permit withdrawals at relatively long intervals, such as one quarter with some pre-notification requirement. On the other hand, the effectiveness of these institutional arrangements in eliminating limits to arbitrage is not clear. We do find some circumstantial evidence that concerns about short-run performance and fund flows matter for hedge funds as well.

A more radical view is that institutional investors *induce bubbles* in order to benefit at the expense of individual investors. In DSSW (1990b) rational traders aggressively buy the asset after some initial good news, knowing that boundedly rational feedback traders will push up the price even further. Allen and Gorton (1993) argue that bad fund managers have

incentives to churn a bubble since they share the profit, but not the loss. Given the relatively small magnitudes of hedge fund stock holdings, we think it is less likely that hedge funds move prices across the board in an entire market segment to exploit behavioral traders or their own clients. It is perceivable however, that hedge fund managers could deliberately induce bubbles in some individual stocks. Our data provides some examples that are at least suggestive of that.

Furthermore, Ofek and Richardson (2001) argue that arbitrageurs might be unable to exploit some mispricing, because they face high *transactions costs* or *trading restrictions*. During the technology bubble, short selling was difficult for ‘special’ stocks since lock-up periods severely restricted the number of lendable assets. While this explanation for overpricing is convincing for certain stocks, Geczy, Musto, and Reed (2001) argue that it does not apply for a large majority of stocks, including many internet stocks.

Our paper is also related to recent empirical work on limits to arbitrage. Mitchell, Pulvino, and Stafford (2001), Baker and Savasoglu (2002), and Pontiff (1996) analyze limits to arbitrage in the context of corporate events and closed-end funds, respectively. Wurgler and Zhuravskaya (2002) investigate the role of idiosyncratic risk in limiting arbitrage. Our paper also contributes to the growing literature on hedge funds. Following Fung and Hsieh (1997), a literature has developed which seeks to understand the trading strategies and characteristics of hedge funds by regressing their returns on explanatory factors (Agarwal and Naik 2000, Brown and Goetzmann 2001). However, the objective of this literature is to ascertain the properties of hedge fund returns and manager skill, rather than to understand their role as arbitrageurs. Notable exceptions are Brown, Goetzmann, and Park (1998), who attempt to infer hedge fund positions from their returns to investigate their role in the Asian currency crisis, and Fung and Hsieh (2000), who perform similar analyses for several events. Both papers however differ from ours in that they look at *returns* only and infer holdings indirectly—a difficult undertaking given the wide set of investment opportunities available to hedge fund managers.

3. Data and sample characteristics

3.1 Returns on NASDAQ 1998-2000

In our analysis of hedge fund holdings we want to focus on those companies that were likely to be most overvalued during the bubble period. To identify candidate firms we use the ratio of Price-to-Sales (P/S). Other commonly used price/fundamental ratios such as Market-to-Book and Price-to-Earnings suffer from the fact that many of the companies with rocketing stock prices during our sample period had extremely negative earnings. Based on Price-to-Earnings ratios it is then hard to distinguish an overpriced internet company from, say, a distressed “old economy” manufacturing company. For this reason we prefer the P/S ratio.

Figure 1a graphs value-weighted return indexes of NASDAQ stocks with different P/S ratios from 1998 to 2000. We use monthly stock returns from CRSP and accounting data from the CRSP/COMPUSTAT merged database. At the end of each month, we rank stocks based on their P/S ratio using sales figures that are lagged at least six months and end of month market capitalization. We then sort all stocks into five equally spaced groups based on NASDAQ breakpoints. These portfolios are rebalanced every month. Figure 1a shows that the value of high P/S stocks quadrupled over the course of about two years until March 2000. However, more than half of these gains were already wiped out by the end of 2000. Interestingly, this extreme mispricing was not a pervasive phenomenon on NASDAQ. The run-up in prices until March 2000 was obviously confined to the subset of stocks with the highest P/S ratios. Figure 1b presents value-weighted averages of turnover (trading volume divided by shares outstanding) for stocks in each portfolio. It shows that trading activity in high P/S stocks was extremely high and increasing throughout the sample period.³

³ Note that turnover for NASDAQ stocks as presented in figure 1b is not directly comparable to NYSE turnover due to the double-counting of dealer trades on NASDAQ.

The return and volume histories of our high P/S portfolio closely mirror the results presented in Ofek and Richardson (2002) for a sample of internet stocks, which saw price increases of about 1000 percent (equal-weighted) from the start of 1998 to March 2000. Hence, our parsimonious P/S grouping apparently does a good job in capturing the subset of stocks that was overpriced. In the rest of the paper we focus mainly the high P/S group, which saw the most extreme price moves during the 1998-2000 period.

3.2 Data on hedge fund holdings

We use data on stock holdings of hedge fund managers from the CDA/Spectrum Database maintained by Thomson Financial, which is based on 13F filings with the SEC. Since 1978 all institutions with more than \$100 million under discretionary management are required to disclose their holdings to the SEC each quarter on form 13F. This concerns all long positions in section 13(f) securities greater than 10,000 shares or \$200,000, over which the manager exercises sole or shared investment discretion. 13(f) securities include U.S. stocks, some equity options and warrants, shares of closed-end investment companies, and some convertible debt securities. These reporting requirements apply regardless of whether an institution is regulated by the SEC or not, and it also applies to foreign institutions, if they “use any means or instrumentality of United States interstate commerce in the course of their business.” Hence, it also applies to hedge funds, provided that holdings of 13(f) securities exceed the specified thresholds.⁴ The reporting entity is the institution, not the fund. For example, all holdings of Soros Fund Management are aggregated into one position. It is not revealed which of these pertain to, say, the Quantum Fund, which is one of the funds managed by Soros.

The CDA/Spectrum database offers a classification of managers into banks, mutual funds, insurance companies, investment advisors, and others. Hedge fund managers generally

⁴ The SEC provides detailed information and a 13F FAQ page on these reporting requirements at www.sec.gov. Gompers and Metrick (2001) provide detailed summary statistics and further information about the CDA/Spectrum database.

appear in the investment advisors and others categories, but this classification is obviously too broad for our purposes. For this reason we turn to other sources to identify hedge fund managers. We identify hedge fund managers from the first quarter of 1998 issue of the *Money Manager Directory* published by Hedge Fund Research, Inc. (HFR), a table on hedge fund performance published in the February 19, 1996 issue of *Barron's*, and a list of hedge fund managers with assets under management in excess of \$500 million as of December 1995 in Cottier (1997). The period we investigate in this paper is 1998-2000. We use only sources prior to the start of this period to ensure that our hedge fund sample is not biased towards ex-post more successful funds.

We look up each candidate hedge fund manager by name in the CDA/Spectrum database. We find records for 71 managers. These are relatively large managers, which hold sufficient amounts of 13(f) securities to exceed the \$100 million reporting threshold. In a second step, we discard some managers because hedge fund assets only make up a small part of their aggregated institutional portfolio reported in their 13F filings. For example, Montgomery Asset Management is one of the candidate hedge fund managers in our sample, but its 13F filings also include the positions of its large mutual fund business and other non-hedge products. This is a consequence of the fact that 13F filings disclose holdings at the level of the institution, not the fund. We apply the following selection criteria. For each manager we check whether the firm is registered as investment adviser with the SEC. Registration is a prerequisite to conduct non-hedge fund business such as advising mutual funds and pension plans. If the firm is not registered, we include it in our sample. This is the case for most large well-known managers such as Soros Fund Management or Tudor Investment Corporation, for example. If the manager is registered, we obtain registration documents (Form ADV). For a registered firm to be eligible for our sample, we require (a) that at least 50 percent of its clients are “Other pooled investment vehicles (e.g., hedge funds)” or “High net worth individuals”, and (b) that it charges

performance-based fees. This process leaves us with 53 hedge fund managers. Commonly, each firm manages multiple funds, so our sample comprises stock holdings of probably several hundred different hedge funds.

Having identified the managers, we extract their quarterly holdings from the first quarter of 1998 to the last quarter of 2000. Fund Managers are only required to disclose their long positions. 13F filings do not contain information on short positions or options written. Since the willingness to take significant short positions is one of the defining characteristics of hedge funds, the unavailability of short positions data is clearly a limitation. However, for reasons that we explain in more detail below, we believe that long positions still provide an interesting and informative account of hedge funds' trading activities.

Since we investigate a relatively small sample of institutions, we take particular care to adjust properly for the effects of late filings and changes in shares outstanding. As pointed out by Gompers and Metrick (2001), CDA/Spectrum data has the unwieldy property that late filings after the 45 day deadline set by the SEC reflect stock splits that have occurred between the end of the quarter and the filing date. We use adjustment factors to undo this split adjustment, and to make the report comparable to those of on-time filers. In very few cases the filing is more than three months delayed. We discard these observations. For 16 manager-quarter observations in our hedge fund sample there is a missing report. In this case we assume that holdings remained unchanged from the quarter preceding the missing report. We properly adjust for splits in this case, too.

3.3 Summary statistics

Table 1 provides some summary statistics on our sample. As this paper is the first piece of research that looks at hedge fund stock holdings, the information in Table 1 is important. The first column shows the number of managers for which we have a valid report. All of the 53

managers in our sample existed in the first quarter of 1998. The reason for why some do not have 13F filings in the early quarters of the sample is either that they did not hold U.S. stocks or other 13(f) securities at all, or that their total holdings of 13(f) securities were not above the \$100 million threshold. They may also disappear for these reasons.

The second set of columns contains statistics on the distribution of stock holdings across managers. For these statistics we add the total market value of all NYSE/AMEX/NASDAQ stock holdings for each manager. Compared with mutual fund managers, the mean holding of about \$1 billion is small.⁵ The median is much lower, which indicates that the distribution is skewed, with a few large managers accounting for the bulk of stock holdings. The five managers with the largest holdings in the first quarter of 1998—Soros Fund Management, Tiger Management, Omega Advisors, Husic Capital Management, and Zweig Di-Menna Associates—account for about 60 percent of total stock holdings. Because of this skewness we report the semi-interquartile range (one half of the difference between the 75th and the 25th percentile) as a measure of cross-sectional dispersion in our summary statistics, and not the cross-sectional standard deviation.

Aggregate holdings, reported in the last column, fluctuate between \$31 billion and \$50 billion. For comparison, TASS and MAR/Hedge, two of the major data providers in this area, estimate the total assets under management in the hedge fund industry at the beginning of 2000 to be between \$150-200 billion. We do not know the amount of leverage used by the funds in our sample, but since extreme LTCM-like leverage is the exception rather than the rule, we are probably safe to conclude that we capture a significant part of total hedge fund stock holdings.

The third set of columns shows the number of stocks held by the hedge fund managers in our sample. With the mean at about 100 stocks and the median around 50, these numbers show that hedge fund holdings are fairly concentrated, which is somewhat typical for active

⁵ Gompers and Metrick (2001) report that the average mutual fund institution (which usually comprises multiple funds) in the Spectrum database in 1996 managed in excess of \$10 billion.

managers who make deliberate bets on a relatively small group of stocks or single segments of the market.

In the fourth set of columns we report the approximate portfolio turnover. We follow the CRSP mutual funds database and Wermers (2000) and define turnover as the minimum of the absolute values of buys and sells of a manager in a given quarter, divided by her total stock holdings. This definition of turnover captures trading unrelated to in- or outflows. Since we calculate it from quarterly holding snapshots, it is understated. Even so, this turnover measure provides an important diagnostic. Perhaps hedge funds trade so actively that the bulk of their trades are intra-quarter in-out trades in the same stock, which leave no trace in quarterly holdings. In this case, holdings at a quarterly frequency would not provide much useful information on their true trades, and portfolio turnover would be close to 100 percent per quarter. Our numbers in table 1 however show that it is much lower. Quarterly turnover is about 25 percent (100 percent annualized). This is somewhat higher than turnover for the average mutual fund, which Wermers (2000) found to be 72.8 percent (annualized) in 1994, but it still suggests that quarterly holdings do contain useful information about trades. Obviously, a substantial part of holdings survives from one quarter to the next. This suggests that there is some low frequency component in their strategies that is captured well by quarterly holdings snapshots. It is precisely this low frequency component that we are most interested in—that is, the overall allocation to a large market segment, rather than high-frequency trades in individual stocks.

We also note that the hedge funds in our sample generally only hold around 0.3 percent of outstanding aggregate equity.⁶ This is not surprising, as aggregate stock holdings of hedge funds in our sample (about \$30-50bn) are dwarfed by holdings of other institutional investors,

⁶ Fung and Hsieh (2000) estimate indirectly from returns that the large hedge funds in their sample held about 0.2 percent of U.S. equities in October 1987. Compared to this figure, our numbers appear reasonable, given the expansion of the hedge fund sector as a whole since 1987.

such as mutual funds and pension funds. These relatively small holdings of hedge funds imply that we cannot say much about causal links between changes in hedge fund holdings and price changes. In any case, our interest in this paper centers on understanding the trading behavior of close-to-rational arbitrageurs when faced with a bubble, not on price impact. The hedge fund managers in our sample are certainly not the only sophisticated and close-to-rational players in the market, but we believe that they are representative for this class of investors, which allows to infer some general lessons about the limits of rational arbitrage.

4. Did hedge funds trade against the bubble?

The first point we want to establish is whether hedge funds were attacking the bubble in technology stocks—by selling their holdings in this segment, or even by going short—or whether hedge funds were riding the bubble. According to the classical view, rational arbitrageurs should short assets they know to be overpriced. By contrast, the Abreu and Brunneimeier (2001) model shows that they may want to ride bubbles for a while. For the time being, our working assumption is that hedge fund managers were aware of the bubble in technology stocks—for example, because they performed the back-of-the-envelope calculation of Ofek and Richardson (2001) we mentioned in the beginning. Of course, we also need to entertain the possibility that they failed to spot the bubble. We defer this issue until the next section. We start by analyzing the weight of technology stocks in hedge fund stock portfolios. To assess the effect of hedge fund short positions and derivatives, we also look at returns of hedge funds.

4.1 Exposure to technology stocks: Portfolio weights

At the end of each quarter, we sum up all the holdings retrieved from 13F reports to compile the aggregate hedge fund portfolio. As explained above, we define the technology

segment as the high price/sales quintile of the NASDAQ, as this is a parsimonious way of capturing the most overpriced stocks. We compute the total market value of holdings in the NASDAQ high P/S segment, and compare them to the total market value of all hedge fund stock holdings. For comparison, we also compute the weight of NASDAQ high P/S stocks in the market portfolio of all NYSE/AMEX/NASDAQ stocks on CRSP.

Figure 2 shows the evolution of these weights over time. The weight of technology stocks in the aggregate hedge fund portfolio is represented by the columns, the line shows the corresponding weights in the market portfolio. The first striking fact in this figure is that hedge funds were generally overweight in technology stocks. For example, when the NASDAQ peaked in March 2000, hedge funds had devoted 31 percent of their stock portfolio to this segment. For comparison, these stocks only commanded a weight of 21 percent in the market portfolio at that time.

The evolution of these weights over time also reveals some interesting patterns. Following the build-up of an overweight position in late 1998, hedge funds subsequently reduced their exposure. This is at least somewhat consistent with the remark of Soros Fund Managements' then-chief investment officer (quoted in our introduction) that they were "calling the bursting of the internet bubble" in spring 1999. As it turned out, this call was too early. And while a reduction in weight is apparent, the move does not appear aggressive—after all, hedge funds continued to be overweight, despite the reduction. The reaction to the failure of the bubble to burst however is more dramatic. Within just one quarter, hedge funds increased the weight of technology stocks from 16 percent to 29 percent in September 1999. The market portfolio weights only changed from 14 percent to 17 percent. Interestingly, this increase occurred just before the final price run-up of technology stocks. From the end of September 1999 to February 2000, the high P/S segment of the NASDAQ gained almost 100 percent (see Figure 1a). The

overweight then gradually declines over the following quarters. At the end of 2000 the weight is very close to the market portfolio weight.

Overall, there is no evidence that hedge funds engaged in a substantial attack on the technology bubble. Until March 2000 their trading supported, rather than undermined the bubble. Hedge Funds were riding the bubble, not fighting it. From a classical perspective, these results are puzzling. Why would some of the most sophisticated investors in the market hold these overpriced technology stocks? And, even more puzzling, why would they even be overweight in these stocks?

Apart from our working assumption that hedge fund managers knew about the bubble, this initial analysis leaves open two more questions. First, there is certainly a possibility that hedge funds took short positions in technology stocks, which are not captured with our long-only holdings data. If this were the case, looking at long positions would clearly be misleading. We deal with this issue in the next subsection. Second, one might suspect that hedge funds may have reacted to the bubble by pulling out of stocks altogether, not just technology stocks—a move that would not leave a trace in the portfolio weights in Figure 2. However, the aggregate hedge fund stock holdings shown in the summary statistics in Table 1 do not suggest that such a pull-out took place.

4.2 Exposure to technology stocks: Return regressions

A shortcoming of the analysis up to this point is that we could not analyze the short positions of hedge funds. However, this problem may not be as severe as it appears. If hedge funds established short positions in high P/S stocks in response to pervasive overpricing, it seems likely that they would also reduce their long positions in this segment. The exception may be funds that specialize on relative value and event-driven arbitrage, which are more likely to have short and long positions in the same segment. But these funds are relatively

uninteresting for our purposes anyway, as they do not attempt to arbitrage valuation differences across broad market sectors or asset classes.

Nevertheless, to find out if long-only data is misleading in this respect, we examine returns of hedge funds. We use these returns in factor regressions to obtain hedge funds' exposure to the NASDAQ high P/S segment indirectly. First, we obtain performance data for five hedge funds managed by the five managers with the largest stock portfolio at the start of our sample period.⁷ We construct an equal-weighted index of their returns. Second, we analyze hedge fund style indexes compiled by *Hedge Fund Research, Inc.* (HFR). HFR groups hedge funds according to their investment style and calculates performance indexes for each group. The HFR database includes non-surviving funds. It has been used in prior research, for example Agarwal and Naik (2000). Returns are net of fees. We select those styles that are likely to have significant exposure to equities (we discard fixed income styles, for example).

To make inferences about the exposure to the technology segment, we run monthly time-series regressions of hedge fund index returns R_t on the CRSP value-weighted NYSE/AMEX/NASDAQ market index $R_{M,t}$ and the return on the NASDAQ high P/S segment R_{HIGH} minus the market return. We call the second factor the TECH factor.

$$R_t = \alpha + \beta R_{M,t} + \gamma (R_{HIGH,t} - R_{M,t}) + \varepsilon_t \quad (1)$$

Positive loadings γ on the TECH factor then indicate that, within their portfolio of stocks, funds have relatively more long exposure to NASDAQ high P/S stocks than the market portfolio.⁸

Underweight and short exposure leads to negative loadings. This regression approach to infer

⁷ We have data for one fund per manager. The data source is a merged database of MAR, TASS, and HFR. We thank Narayan Naik and Subhra Tripathy at the LBS Centre for Hedge Fund Research and Education for providing these data. Unfortunately, agreements with data vendors prevent us from disclosing the performance of individual hedge funds.

⁸ Some recent papers document that hedge funds tend to have non-linear risk exposure, reflecting their use of derivatives and dynamic trading strategies (Fung and Hsieh 1997, Agarwal and Naik 2000), which may lead to a misspecification of linear factor models. However, for funds engaged mainly in equity market investments that we focus on here, this seems to be less of a problem. An informal check of scatterplots of hedge fund style index returns against factor returns does not reveal much non-linearity. Hence, we do not have reason to believe that our simple linear factor suffers from such problems.

hedge fund positions is similar to Brown, Goetzmann, and Park (1998). We run these regressions with monthly returns over the period 1998-2000. We first look at the exposures estimated over the entire sample period. To get an idea about how exposures change over time, we then employ rolling regressions over 12-month windows.

Table 2 presents factor loadings estimated over the entire period 1998-2000. The first column of coefficients shows loadings on the market factor, the second column shows coefficient estimates for the TECH factor. Panel A reports the result for the index of large manager funds (LARGE). The estimated coefficients show that, on average, the largest hedge fund managers in our sample had positive exposure to the TECH factor. The coefficient on the TECH factor is significant at conventional significance levels (t -statistic 2.51). Market exposure is positive as well. This result is consistent with our earlier finding that hedge funds were overweight in high P/S NASDAQ stocks. A positive coefficient on the TECH factor means precisely that. Hence, we have no reason to believe that the hedge funds in our sample engaged in extensive shorting of technology stocks. At a minimum, their short positions were too small to turn over our finding of an overweight on technology stocks.

Panel B repeats the same exercise for different HFR style categories (the Appendix provides a brief description of these). Since our sample of hedge funds and the HFR universe are only partly overlapping, this analysis also provides a useful robustness check. A first glance at the results shows that coefficients on the market factor have the signs and magnitudes we would expect given the style categories. Equity-Market Neutral funds have approximately zero loadings on the market factor. Equity Non-Hedge funds, which focus on long positions, have a market beta closer to one. Short-Selling Specialists, on the other hand, have strongly negative market betas. With respect to loadings on the TECH factor, we find that Equity Non-Hedge and Equity-Hedge funds show the same patterns we observed in Panel A. Both have highly significant positive exposure to the TECH factor. For Market-Timing funds, Macro funds, and

Equity Market-Neutral funds the coefficient is also positive but at a smaller magnitude. Not surprisingly, Sector Technology funds have the highest exposure to the TECH factor, an artifact of their sector focus. More interestingly, Short-Selling specialists are the only ones with negative exposure to the TECH factor. Their returns moved almost exactly inverse to market returns, and for every percent the NASDAQ high P/S segment return underperformed the market, they earned 0.44 percent.

Of course, these regressions only yield the average exposure over the entire sample period. We would also like to know whether the time pattern of exposures estimated from returns matches the pattern we found in holdings. We have to entertain the possibility that short exposure of hedge funds was concentrated in a short period, for example during 1999, which might not show up in the full-period average. To address this point, we re-run the regressions of Table 2 as rolling regressions over 12-month windows. In the interest of parsimony, we group all HFR styles except short-selling specialists into one equal-weighted index, denoted HFR. Short-selling specialists (HFR SHORT) are considered separately.

The results are presented in Figure 3. The top graph shows the evolution of exposure to the TECH factor. Turning first to the factor loadings of LARGE, their evolution over time fits well with the evidence on portfolio weights examined earlier. For comparison, the line denoted 13F shows the factor sensitivities of a hypothetical aggregated hedge fund portfolio, constructed by adding up positions obtained from our quarterly 13F holdings data across all hedge funds. Until September 1999, TECH factor sensitivities estimated from actual performance data (LARGE) and long-only holdings data (13F) are almost identical. This provides further evidence that hedge funds did not offset their long exposure to the technology segment with short positions. After September 1999, the extent of short positions appears to have increased, but not strongly enough to overturn the technology overweight in long positions. Our analysis in Figure 2 therefore does not miss much in this respect. A comparison of LARGE and 13F in

Figure 3b however shows that short positions, possibly in futures, were used to reduce exposure to the overall market. This is not surprising, as many hedge funds follow market-neutral strategies. Overall, the close co-movement of 13F and LARGE factor sensitivities is reassuring. It shows that our long holdings data reveals essential characteristics of hedge fund portfolios.

The regression coefficients of LARGE on the TECH factor indicate an overweight on technology stocks during almost the entire sample period. The short dip into negative territory for the regression windows ending in October and November 1999 is consistent with the reduction in high P/S portfolio weights during the first two quarters of 1999. The exposure to TECH is highest in regression windows that straddle the first quarter of 2000, the time period when long positions also showed the most extreme overweight of high P/S stocks. The TECH loadings of HFR largely mirror these results, albeit with less fluctuations.

The exposure of short-selling specialists however shows remarkable timing. Until September 1999, their exposure is well described as being short the market portfolio, without any directional bias concerning the technology segment. Yet, after this date, they obviously started going short on technology stocks. By the time of the NASDAQ peak in March 2000 they already had a strong short exposure. The essence is that even these funds, which do not do much else than shorting, did not attack the bubble before it was close to burst.

Overall, the rolling regressions confirm that our long positions data does not paint a misleading picture of hedge funds exposure to technology stocks. In the remainder of the paper we therefore return to our holdings data, as these allow to investigate questions that cannot be addressed with returns data—in particular, the trades of hedge funds in individual stocks.

4.3 Portfolio weights of individual managers

So far we have couched our analysis in terms of the aggregate hedge fund portfolio, but decisions about attacking or riding a bubble rest with individual managers. They may come up

with different solutions to this timing problem. To get an idea about the approach taken by different managers we examine the portfolios of the five managers with the largest stock holdings at the start of 1998. As we reported earlier, these five managers account for about 60 percent of aggregate stock holdings in our sample. Similar to the analysis in Figure 2, we compute the weight of high P/S NASDAQ stocks—this time for individual funds—and compare them to the corresponding weights in the market portfolio.

Figure 4 graphs the portfolio weights for each manager. The results are consistent with anecdotal evidence on these managers' strategies. The proportion invested into technology stocks by Tiger Management, for example, a well-known value-manager, is low. In 1999 Tiger eliminated virtually all investments in this segment. This is consistent with the widely reported refusal of Julian Robertson, manager of the Tiger Fund, to buy into the internet bubble. While the weights of Tiger and of Soros Fund Management were not much different at the end of 1998, they took two radically different paths in 1999. During the third quarter of 1999 Soros increased the proportion invested in the technology segment from less than 20 percent to about 60 percent. Zweig-DiMenna and Husic also decided to keep an overweight of high P/S stocks. Omega, in contrast, structured the portfolio more along the lines of Tiger.

Interestingly, the two managers with the highest exposure to technology stocks in September 1999 experienced large subsequent fund inflows. The hedge fund data provider MAR/Hedge reports that in November 1999 Soros and Zweig-DiMenna came in top in the fund flows league table, with inflows of \$250.8 million for Soros and \$134.4 million for Zweig-DiMenna. In contrast, Tiger's very different fate highlights the danger of betting against a bubble. As the burst of the bubble failed to materialize in fall of 1999, Tiger increased the redemption period for investors from three to six months in order to curb outflows.⁹ After mounting losses, Robertson announced the fund's liquidation in March 2000, just when prices

⁹ New York Times, October 8, 1999, Section C, p. 22.

of technology stocks started to tumble.¹⁰ The fact that the manager positioned most strongly against the bubble had to liquidate just before the bubble peaked illustrates well the liquidation risk, and the resulting limits to arbitrage highlighted in Shleifer and Vishny (1997). Unlike Tiger, the managers who chose to ride the bubble are still around.

5. Did hedge funds time their exposure in individual stocks?

Having established that hedge funds were riding the bubble, we turn now to the important question whether hedge funds did so deliberately—as predicted by the Abreu and Brunnermeier (2001) model—or whether they simply failed to understand that a bubble had developed. The lack of evidence that hedge funds exited the technology stock segment aggressively close to the peak of the bubble implies that this is a plausible alternative hypothesis. Yet, looking at the aggregate segment perhaps obscures successful timing at the individual stock level. After all, the fact that the NASDAQ high P/S segment peaked in March 2000 does not mean that all member stocks peaked in that quarter. This is underscored by Table 3, which shows the number of stocks that peaked in each quarter from 1999 to 2000. Many stocks peaked before or in quarters subsequent to March 2000. Hence, it is possible that hedge funds' holdings of technology stocks in 2000 were well timed in the sense that they were concentrated in stocks that did not crash yet. We investigate this possibility in this section.

5.1 Hedge fund holdings around stock price peaks

To judge the timing skills of hedge fund managers, we look at hedge fund holdings around the price peaks of individual stocks. For each stock we construct a quarterly total return index from 1998 to 2000. We define the price peak as the quarter-end at which this index takes its maximum value. To ensure that we can observe holdings several quarters before the peak, we

¹⁰ Tiger Management sold most of its holdings and returned funds to investors during the first half of 2000 (Financial Times, March 31, 2000, p.28). For this reason we did not include it anymore after March 2000.

restrict attention to stocks peaking in 1999 or 2000. For each stock we also calculate the proportion of outstanding shares that is held by hedge funds. Using an event study framework, we align these quarterly series of hedge fund holdings in event time. Event-time quarter 0 is the quarter of the price peak. We then take a value-weighted average of the proportions held by hedge funds across stocks within three different samples: High P/S NASDAQ stocks, other NASDAQ stocks, and NYSE/AMEX stocks.

Figure 5 presents the result. The first point to note is that for high P/S NASDAQ stocks, hedge funds owned a greater proportion of outstanding equity before than after the price peak. They hold the maximum share of 0.54 percent one quarter before the price peak. At the time of the peak this is already reduced to 0.40 percent.¹¹ Holdings show a further decline in the post-peak quarters in which average returns are negative. Interestingly, hedge funds seem to be much more successful in timing their investments within the high P/S segment of the NASDAQ than within other market segments. While hedge fund holdings before price peaks in the technology segment are almost twice as high as for NYSE/AMEX stocks, there is not much difference several quarters after the peak.

Hence, more so than the aggregate holdings data in Figure 2, these results suggest that hedge funds did successfully time their exit of the bubble. In pre-peak quarters hedge funds held about twice as many shares as in post-peak quarters. For technology stocks the average returns in the post-peak quarters are in the range of -20 percent. Hedge funds managers let other investors bear a greater share of this price collapse than of the price run-up before the peak. In the end, it is, of course, not possible to demonstrate with certainty that hedge fund managers knew about the bubble. However, based on this evidence, we judge that it is unlikely that they did not.

¹¹ Standard errors for these event-time averages are 0.02 percent for NYSE/AMEX stocks, and they vary between 0.02 percent and 0.04 percent for NASDAQ stocks.

The fact that the timing efforts were most successful in the technology segment is further consistent with the intuition expressed, for example, in DSSW (1990b) and Abreu and Brunnermeier (2001), that price bubbles present particularly good profit opportunities to rational arbitrageurs, if the sentiment of uninformed investors supporting the bubble is predictable to some extent. These potential timing gains are precisely the reason why riding a bubble can be a rational strategy in these models.

5.2 A closer look at some internet stocks

To get further insight into how this bubble-timing game was carried out at the micro level, we take a look at some individual stocks. In spring of 1999, Richard Thaler conducted a survey of professional investors, asking for their opinions on valuation levels of five internet stocks (Thaler 1999). The median response was that a portfolio of America Online, Amazon.com, eBay, Priceline.com, and Yahoo! was 100 percent overvalued. Given this apparent consensus on mispricing, it is an interesting question to see what hedge fund managers actually did. Since hedge fund holdings for America Online during the period leading up to its acquisition of Time Warner may be affected by risk arbitrage activities, we replace it by Qualcomm. With a return of about 2,600 percent, Qualcomm was the best performing stock on NASDAQ in 1999 and hence an interesting case. For these stocks we compute the proportion of outstanding equity held by hedge funds, and the return for each quarter, depicted in Figure 6.

The picture that emerges from this figure can be summarized as follows. When returns were positive—frequently in the range of 50 percent or 100 percent per quarter—hedge funds had considerable holdings. But this exposure was drastically reduced before prices collapsed. The prices of Qualcomm and Yahoo! peaked in December 1999, accompanied by a drastic reduction in holdings in the same and in the following quarter. Amazon.com peaked in March 1999, and subsequent holdings are much lower. eBay saw its peak in March 2000, again

accompanied by reductions in hedge fund holdings. Only for Priceline.com the picture is less clear. This fits well with our event study evidence from above.

The extraordinary spike for Qualcomm in September 1999 deserves some special attention. Hedge fund holdings shot up to 6 percent of outstanding equity. It turns out that most of these trades originated with Soros Fund Management.¹² The figure shows that this investment paid off handsomely in the next quarter. These patterns are at least suggestive of behavior along the lines of the DSSW (1990b) feedback-trading model. It is perceivable that the bubble in Qualcomm may have been further inflated by Soros' trading activities, which in turn prompted further buying of positive feedback traders in subsequent periods. But to verify this, one would have to conduct further tests that are beyond the scope of this paper. Overall, these results on timing in individual stocks underscore the fact that hedge funds did not exert a correcting force on prices until the bubble was about to burst.

5.3 Performance evaluation

If hedge fund managers indeed had skill in picking stocks and in timing the bubble on an individual stock level, this should also be detectable in a standard performance evaluation framework. In this subsection we therefore look at portfolios that replicate the holdings and trades of hedge fund managers—to the extent they are visible in our quarterly holdings data. We compare them to suitable benchmark portfolios to determine abnormal performance.

To assess performance, we form two portfolios. The first one—we call it ‘Copycat’ portfolio—mimics holdings of hedge funds. In essence, we calculate the return to a hypothetical fund, which, at each quarter end from March 1998 to December 2000, obtains 13F filings data,

¹² Qualcomm's public float at the end of 2000 was approximately 79 percent of shares outstanding, which further raises Soros stake in terms of freely floating shares (see the first quarter of 2000 investor fact book at www.qualcomm.com).

and invests in aggregate hedge fund shareholdings.¹³ We form three of these copycat funds, one for the NASDAQ high P/S quintile, one for other NASDAQ stocks, and one for NYSE/AMEX stocks. Within each copycat fund we weight returns for each stock in proportion to the value of hedge fund holdings. The second portfolio—dubbed ‘Buys-Sells’—mimics trades instead of static holdings. This portfolio takes long positions in stocks bought by hedge funds, and it shorts those they sold. For each stock, portfolio weights are given by the relative values of the net change in aggregate hedge fund holdings. Both portfolios are similar to those used by Chen, Jegadeesh, and Wermers (2000) in a study of mutual fund performance.

To get a first impression of hedge fund performance, Figure 7 plots the total return index of the NASDAQ high P/S Copycat portfolio against the value-weighted return on the entire NASDAQ high P/S quintile. The results are intriguing. The figure shows that around the peak of the bubble—from September 1999 to September 2000—technology stocks held by hedge funds performed much better than other technology stocks. This confirms what we suggested earlier—namely, that in 2000 hedge funds holdings were concentrated in technology stocks that did not really crash yet. The percentage return in the final quarter is about the same for both portfolios.

Turning to a more formal evaluation of performance, we measure abnormal returns with respect to characteristics-matched benchmark portfolios, similar to Daniel, Grinblatt, Titman, and Wermers (1997). To calculate benchmark returns, we sort all NASDAQ stocks into quintiles based on size, and we sub-sort within these groups, first into P/S quintiles, and then into past six-month return quintiles. Returns are value-weighted within each of the resulting 125 benchmark portfolios. We repeat the same exercise for NYSE/AMEX stocks, which yields a second set of benchmark portfolios. We calculate abnormal returns for each stock by subtracting the return of its matched benchmark portfolio.

¹³ Of course, 13F filings are not public yet at the end of the quarter. Owing to the reporting deadline, it takes at least 45 more days for this information to become public. Hence, this copycat fund could not be implemented this way in reality.

Table 4 presents the results. We compute performance measures separately for each of the four quarters following a 13F report. For example, the Copycat portfolio in the first row (Qtr +1) invests in stocks held by hedge funds at the end of March 1998, and it holds them until the end of June 1998, when the portfolio is rebalanced based on end of June 1998 filings, and so on. In the second row (Qtr +2), the June to September 1998 portfolios are build on March 1998 13F filings, the October to December 1998 portfolios are based on June 1998 filings etc. From these time-series of portfolio returns over 12 quarters we compute arithmetic means and t-statistics.

The abnormal returns reported in this table are striking. In the technology segment, the Qtr +1 Copycat portfolio on average outperforms by 4.5 percent per quarter. At close to 4.0 percent per quarter, the abnormal return of the Buys-Sells portfolio is similar. The abnormal returns for both portfolios in Qtr +1 are significantly different from zero at a 10 percent level, which is surprising given that we investigate a sample period of only 12 quarters. The outperformance appears quite long-lived, as Qtr +2 adds some more abnormal returns, albeit at a lower magnitude. There is no reversal of this outperformance in Qtr +3 and Qtr +4. Yet, the outperformance is confined to the technology segment. None of the abnormal returns for other NASDAQ stocks, or NYSE/AMEX stocks comes close to the outperformance figures in the technology segment, nor is there any statistical significance. This confirms our earlier conjecture that profit opportunities for smart investors were greatest in the bubble segment.

6. Conclusions

In classical finance theory rational arbitrageurs prevent price bubbles by trading against mispricing. Limited arbitrage models predict that this mechanism may fail. It may even be optimal for arbitrageurs to ride a price bubble for a while. To shed some light on this fundamental question, we analyze stock holdings of hedge funds during the NASDAQ technology bubble 1998-2000. We present evidence consistent with the limited arbitrage view.

First, we find that overall stock holdings of hedge funds are very small compared to holdings of other institutions such as mutual funds. The small relative size of arbitrageurs highlights the importance of coordination problems: Arbitrageurs are concerned about attacking the bubble too early, without support from their peers.

Second, we show that hedge funds were riding the technology bubble, rather than attacking it. Our holdings data shows that hedge funds devoted a large proportion of their stock portfolios to technology stocks—an overweight proportion compared to corresponding weights in the market portfolio. Hedge fund returns data shows that this long-exposure was not offset by short positions or derivatives. Hedge fund managers picked their stocks well. On a stock-by-stock basis, hedge funds reduced their holdings before prices collapsed. This timing skill shows that it is unlikely that hedge fund managers held technology stocks simply because they failed to recognize the bubble. Deliberate timing appears more plausible. It also suggests that the investor sentiment driving the growth and eventual collapse of the bubble was predictable to some extent, and hedge funds were exploiting this opportunity. Given such predictable investor sentiment and coordination problems among arbitrageurs, riding a price bubble for a while can be a rational strategy for an arbitrageur, as shown in the model of Abreu and Brunnermeier (2001). This model appears to describe well how hedge funds behaved during our sample period. It contrasts with the classical view that arbitrageurs would always stabilize prices by attacking mispricing.

Importantly, our results suggest that frictions, such as short-sales constraints, emphasized in recent work by Ofek and Richardson (2002) and Cochrane (2002), are not sufficient to explain the failure of arbitrageurs to contain the Technology Bubble. Costs and risks associated with short selling can explain why hedge funds were reluctant to take short positions, but they cannot explain our finding that hedge funds invested heavily in overpriced

assets on the long side. Understanding incentives to ride price bubbles seems to be crucial to get a complete picture of how the forces of arbitrage were limited during this extraordinary period.

Finally, we also document some circumstantial evidence supporting the view that arbitrageurs are concerned about short-run performance, which implies short-horizons in evaluating arbitrage opportunities (Shleifer and Vishny 1997). When valuations of technology stocks continued to soar in mid-1999, many hedge funds increased their exposure to technology stocks—exemplified by the switch in strategy by Soros Fund Management after a failed bet against technology stocks. On the other hand, the demise of the Tiger Fund—one of the hedge funds positioned most strongly against the bubble—highlights the danger of persistent betting against a bubble.

Appendix: Hedge fund styles

This appendix provides the definitions of the HFR style indexes, based on descriptions given by HFR (available at <http://www.hfr.com>).

Equity Hedge investing consists of a core holding of long equities hedged at all times with short sales of stocks and/or stock index options. Some managers maintain a substantial portion of assets within a hedged structure and commonly employ leverage. Where short sales are used, hedged assets may be comprised of an equal dollar value of long and short stock positions. Other variations use short sales unrelated to long holdings and/or puts on the S&P 500 index and put spreads. Conservative funds mitigate market risk by maintaining market exposure from zero to 100 percent. Aggressive funds may magnify market risk by exceeding 100 percent exposure and, in some instances, maintain a short exposure.

Equity Market Neutral investing seeks to profit by exploiting pricing inefficiencies between related equity securities, neutralizing exposure to market risk by combining long and short positions. Typically, the strategy is based on quantitative models for selecting specific stocks with equal dollar amounts comprising the long and short sides of the portfolio. A variation is investing long stocks and selling short index futures.

Equity Non-Hedge funds are predominately long equities although they have the ability to hedge with short sales of stocks and/or stock index options. These funds are commonly known as “stock-pickers.” Some funds employ leverage to enhance returns. When market conditions warrant, managers may implement a hedge in the portfolio. Funds may also opportunistically short individual stocks. The important distinction between equity non-hedge funds and equity hedge funds is equity non-hedge funds do not always have a hedge in place.

Macro involves investing by making leveraged bets on anticipated price movements of stock markets, interest rates, foreign exchange and physical commodities. Macro managers employ a “top-down” global approach, and may invest in any markets using any instruments to participate in expected market movements. These movements may result from forecasted shifts in world economies, political fortunes or global supply and demand for resources, both physical and financial. Exchange-traded and over-the-counter derivatives are often used to magnify these price movements.

Market Timing involves allocating assets among investments by switching into investments that appear to be beginning an uptrend, and switching out of investments that appear to be starting a downtrend. This primarily consists of switching between mutual funds and money markets. Typically, technical trend-following indicators are used to determine the direction of a fund and identify buy and sell signals.

Short Sellers specialize in short-selling securities.

Sector: Technology funds emphasize investment in securities of the technology arena. Some of the sub-sectors include multimedia, networking, PC producers, retailers, semiconductors, software, and telecommunications.

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Table 1**Sample summary statistics**

The total sample comprises 53 hedge fund managers that existed prior to 1998, for which we have CDA/Spectrum data, and which satisfy the inclusion criteria described in the text. The number of managers in the first column refers to those with a valid 13F filing in the given quarter. Stock holdings per manager is the sum of the market value of all NYSE/AMEX/NASDAQ stocks held by the manager at the end of the quarter. Portfolio turnover is defined by the minimum of the absolute values of buys and sells during a quarter t , divided by total holdings, where buys, sells, and holdings are measured with end of quarter $t-1$ prices. The means, medians, and the cross-sectional semi-interquartile ranges for portfolio turnover are annualized.

| Year | Quarter | Number of managers | Stock holdings per manager | | | Number of stocks per manager | | | Portfolio turnover | | | Aggregate stock holdings (\$ mill) |
|------|---------|-----------------------|----------------------------|---------------------|--------------------------|------------------------------|--------|-------------|--------------------|------------------|-----------------------|--|
| | | | Mean (\$ mill) | Median (\$ mill) | S.i.q.range (\$ mill) | Mean | Median | S.i.q.range | Mean (ann.) | Median (ann.) | S.i.q.range (ann.) | |
| 1998 | 1 | 35 | 1280 | 295 | 755 | 150 | 56 | 77 | | | | 44,794 |
| | 2 | 42 | 1053 | 231 | 445 | 113 | 50 | 49 | 1.02 | 0.94 | 0.34 | 44,234 |
| | 3 | 42 | 728 | 145 | 364 | 71 | 44 | 30 | 0.83 | 0.57 | 0.40 | 30,594 |
| | 4 | 41 | 925 | 178 | 417 | 66 | 39 | 36 | 1.16 | 1.05 | 0.58 | 37,912 |
| 1999 | 1 | 39 | 1070 | 216 | 538 | 74 | 47 | 39 | 0.98 | 0.84 | 0.55 | 41,742 |
| | 2 | 42 | 995 | 211 | 382 | 75 | 48 | 38 | 1.12 | 1.12 | 0.50 | 41,807 |
| | 3 | 43 | 927 | 244 | 426 | 69 | 37 | 42 | 1.28 | 1.32 | 0.46 | 39,879 |
| | 4 | 44 | 1136 | 270 | 615 | 83 | 46 | 41 | 1.02 | 0.95 | 0.51 | 49,981 |
| 2000 | 1 | 43 | 1138 | 316 | 792 | 85 | 39 | 49 | 1.33 | 1.12 | 0.71 | 48,933 |
| | 2 | 44 | 772 | 246 | 383 | 67 | 37 | 41 | 1.19 | 0.99 | 0.75 | 33,988 |
| | 3 | 45 | 861 | 269 | 413 | 80 | 37 | 34 | 1.21 | 1.22 | 0.63 | 38,747 |
| | 4 | 48 | 812 | 190 | 427 | 100 | 45 | 37 | 1.06 | 0.77 | 0.70 | 38,989 |

Table 2**Exposure of hedge funds to the technology segment: Two-factor return regressions**

This table reports the results of time-series regressions of monthly hedge fund return indexes on R_M , the CRSP value-weighted NYSE/AMEX/NASDAQ market index, and the return on the NASDAQ high P/S portfolio R_{HIGH} minus the market return (the TECH factor).

$$R_t = \alpha + \beta R_{M,t} + \gamma (R_{HIGH,t} - R_{M,t}) + \varepsilon_t$$

Dependent variable in panel A is an equal-weighted index of five funds managed by the five largest managers in our sample. In Panel B left-hand variables are returns on HFR style indexes. The definitions of styles are described in the appendix. β is the estimated coefficient on the market factor, γ is the estimated coefficient on the NASDAQ low S/P factor. $t(\beta)$ and $t(\gamma)$ denote their t-statistics.

| Index | Factor Loadings | | t-statistics | | adj. R ² |
|---|---------------------|--------------------|------------------------|-----------------------|---------------------|
| | β (Market) | γ (TECH) | $t(\beta)$ (Market) | $t(\gamma)$ (TECH) | |
| <i>Panel A: Equal-weighted index of largest funds in our sample (1998-2000)</i> | | | | | |
| Large | 0.42 | 0.17 | (3.51) | (2.51) | 0.56 |
| <i>Panel B: HFR hedge fund style indexes (1998-2000)</i> | | | | | |
| Equity-Hedge | 0.45 | 0.15 | (6.36) | (3.92) | 0.80 |
| Equity Non-Hedge | 0.74 | 0.16 | (9.07) | (3.57) | 0.86 |
| Equity Market-Neutral | 0.07 | 0.01 | (1.54) | (0.53) | 0.10 |
| Market Timing | 0.25 | 0.07 | (3.45) | (1.67) | 0.48 |
| Short-Selling Specialists | -1.00 | -0.43 | (-5.93) | (-4.57) | 0.80 |
| Macro | 0.13 | 0.09 | (1.84) | (2.13) | 0.34 |
| Sector Technology | 0.71 | 0.57 | (5.29) | (7.62) | 0.86 |

Table 3**Distribution of price peaks of NASDAQ technology (high P/S) stocks**

For each stock we construct a total return index from 1998 to 2000 from which we determine each stock's price peak during this period. The table presents the number of stocks peaking per quarter 1999 to 2000. It includes only stocks that belong to the NASDAQ high P/S segment at the time of their peak.

| Year | Quarter | Number of peaks |
|------|---------|-----------------|
| 1999 | 1 | 58 |
| | 2 | 86 |
| | 3 | 38 |
| | 4 | 207 |
| 2000 | 1 | 285 |
| | 2 | 98 |
| | 3 | 198 |
| | 4 | 49 |

Table 4**Characteristics-adjusted performance of stocks held and traded by hedge funds**

At the end of each quarter t we form one portfolio that mimics aggregate hedge funds' holdings (Copycat), based on holdings reported in the end of quarter t 13F filings, and one portfolio that is long stocks bought and short stocks sold by hedge fund managers in quarter t (Buys-Sells). We form three sets of these portfolios: one for the NASDAQ high P/S quintile, one for other NASDAQ stocks, and one for NYSE/AMEX stocks. We compute buy-and hold returns of these portfolios for each quarter $t+1$ to $t+4$. Returns in the Copycat portfolio are weighted by the \$-value of hedge funds holdings (number of stocks times price), returns in the Buys-Sells portfolio are weighted by the relative values of net changes in hedge funds' aggregate positions in quarter t (change in number of stocks times price). Portfolio returns are then averaged in event time. The first row reports the average return in quarter $t+1$, i.e. in the first quarter following the 13F report. The second row reports the return in quarter $t+2$, etc. The two left-hand sets of columns report the average number of stocks and market capitalization of the entire market segment (Total) and the Copycat portfolio. The first formation date is end of March the last one is end of December 2000. Abnormal returns are measured with respect to size, P/S, and past six-month returns characteristics-matched benchmark portfolios. Returns are given in percent per quarter.

| Market Segment | Quarters after 13F | Number of stocks | | Value in \$bn. | | Quarterly Abnormal Returns | | | |
|--|-----------------------|------------------|---------|----------------|---------|----------------------------|----------------|----------------------|----------------|
| | | Total | Copycat | Total | Copycat | Copycat Portfolio | | Buys-Sells Portfolio | |
| | | | | | | Mean | t -statistic | Mean | t -statistic |
| High P/S NASDAQ stocks (Technology Segment) | +1 | 720 | 320 | 2071 | 8.0 | 4.51 | (1.87) | 4.01 | (1.89) |
| | +2 | | | | | 2.71 | (2.02) | 2.78 | (2.65) |
| | +3 | | | | | 0.39 | (0.22) | 0.11 | (0.08) |
| | +4 | | | | | 1.01 | (0.77) | 1.84 | (0.70) |
| Other NASDAQ stocks | +1 | 3163 | 472 | 1236 | 4.1 | 0.55 | (0.58) | 0.91 | (0.72) |
| | +2 | | | | | 0.36 | (0.30) | 0.88 | (0.64) |
| | +3 | | | | | -1.64 | (-1.12) | -0.82 | (-0.60) |
| | +4 | | | | | -0.89 | (-0.55) | 0.65 | (0.31) |
| NYSE/AMEX stocks | +1 | 2118 | 885 | 9891 | 25.0 | 0.24 | (0.31) | 0.12 | (0.16) |
| | +2 | | | | | 0.25 | (0.31) | -0.38 | (-0.52) |
| | +3 | | | | | 0.32 | (0.30) | -0.63 | (-0.74) |
| | +4 | | | | | -0.48 | (-0.45) | -0.98 | (-1.16) |

Figure 1a: Returns

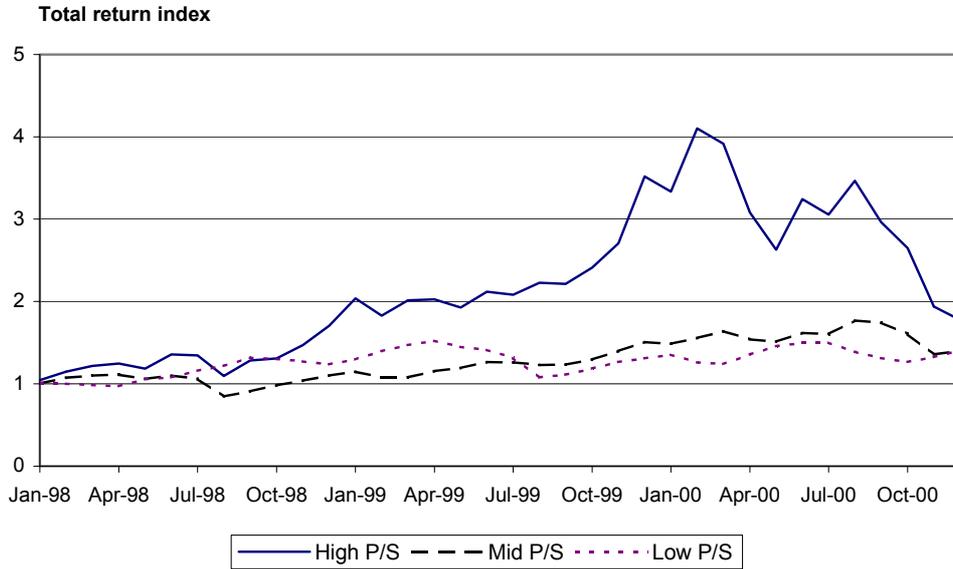


Figure 1b: Turnover

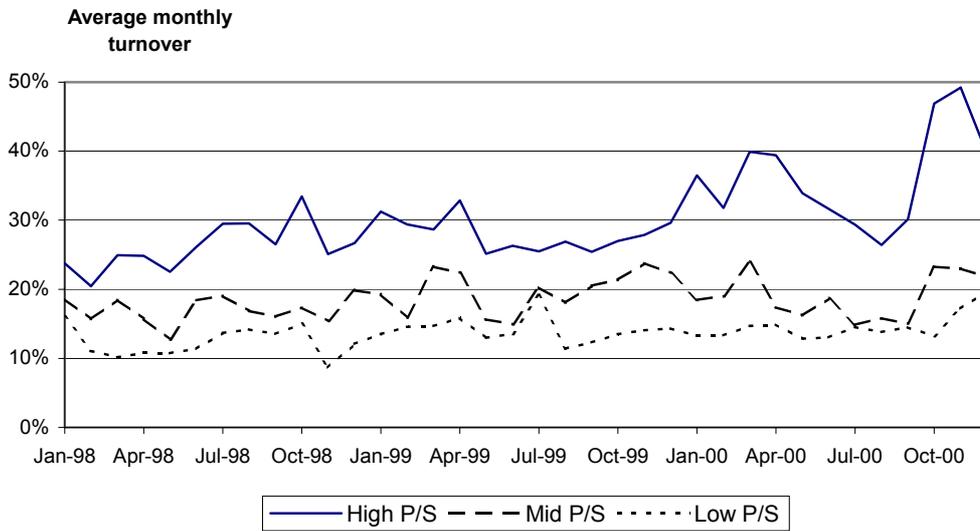


Fig. 1: Returns and trading volume (turnover) for NASDAQ price/sales quintile portfolios 1998-2000. At the end of each month, we rank all stocks on NASDAQ by their price/sales ratio and form five portfolios based on quintile breakpoints. Portfolios are rebalanced each month. The figures show value-weighted averages of returns and turnover, where turnover is defined as monthly trading volume divided by end of month shares outstanding.

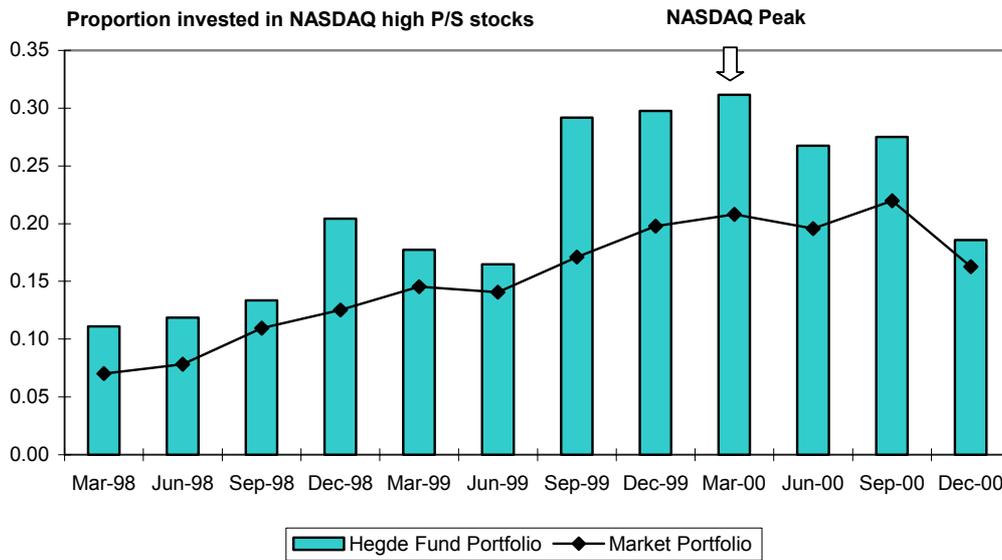


Fig. 2: Weight of NASDAQ technology stocks (high P/S) in aggregate hedge fund portfolio versus weight in market portfolio. At the end of each quarter, we compute the weight, in terms of market value, of high P/S quintile NASDAQ stocks in the overall stock portfolio of hedge funds, given their reported holdings on form 13F. For comparison, we also report the value-weight of high P/S stocks in the market portfolio (all stocks on CRSP).

Figure 3a: Exposure to technology segment (high P/S)

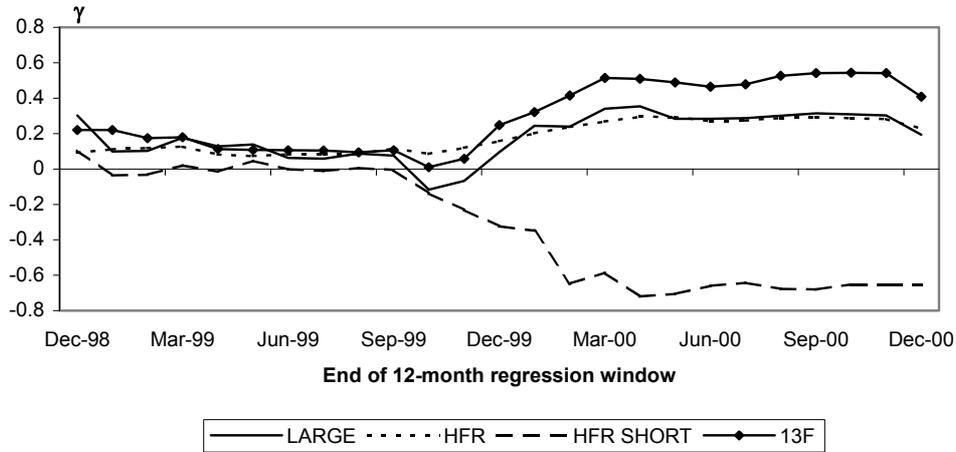


Figure 3b: Market exposure

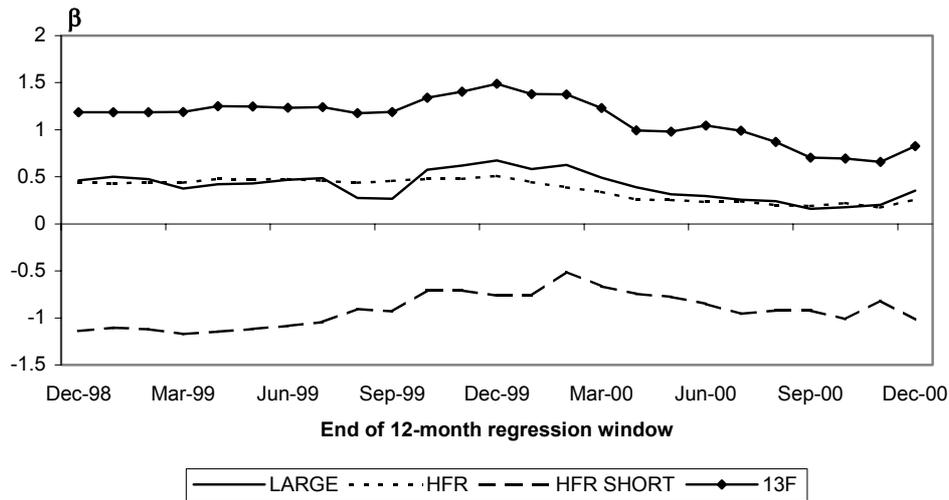


Fig. 3: Exposure of hedge funds to the technology segment: Two-factor rolling regressions. Time-series regressions of monthly hedge fund return indexes on R_M , the CRSP value-weighted NYSE/AMEX/NASDAQ market index, and the TECH factor, which is the return on the NASDAQ high P/S portfolio return R_{HIGH} minus the market return, are run like in table 2. Dependent variables are 13F, the return on the portfolio of aggregate long holdings of all hedge funds from our 13F filings data, LARGE, an equal-weighted average of returns on five funds managed by the five largest managers in our sample, and HFR, which is an equal-weighted average across all HFR style indexes examined in table 2, with the exception of short-selling specialists (HFR SHORT), which are considered separately. Regressions are run monthly over past 12-month windows. Figure 3a shows the estimated coefficients (γ) on the TECH factor, figure 3b shows coefficients on the market factor (β).

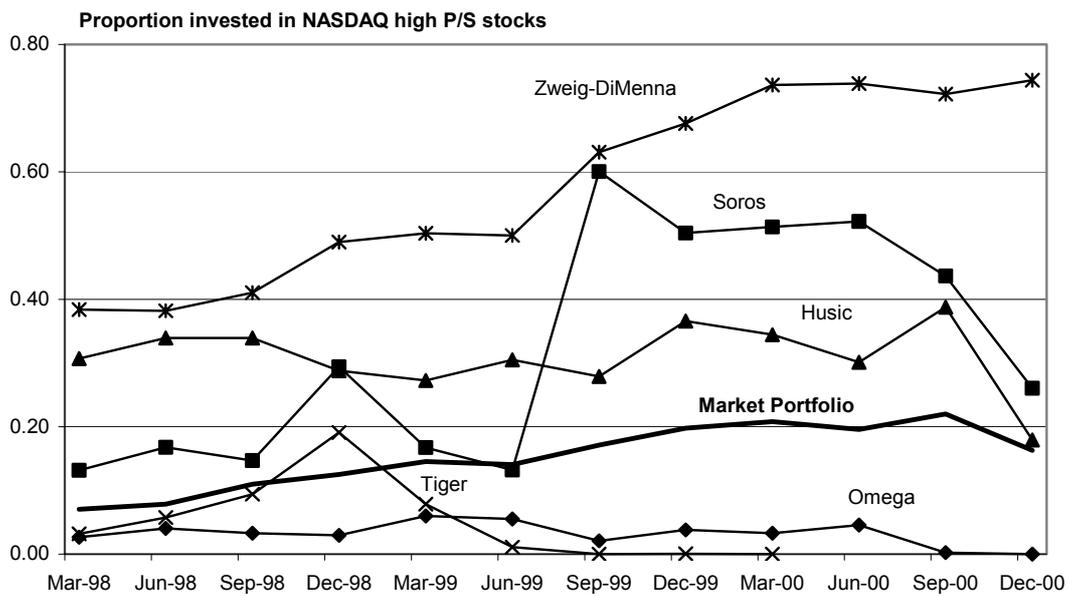


Fig. 4: Weight of NASDAQ technology stocks (high P/S) in individual hedge fund portfolios versus weight in market portfolio. At the end of each quarter, we compute the weight, in terms of market value, of high P/S quintile NASDAQ stocks in the overall stock portfolio of hedge funds, given their reported holdings on form 13F. For comparison, we also report the value-weight of high P/S stocks in the market portfolio (all stocks on CRSP). The figure graphs these weights for the five managers with the largest overall stock holdings in March 1998.

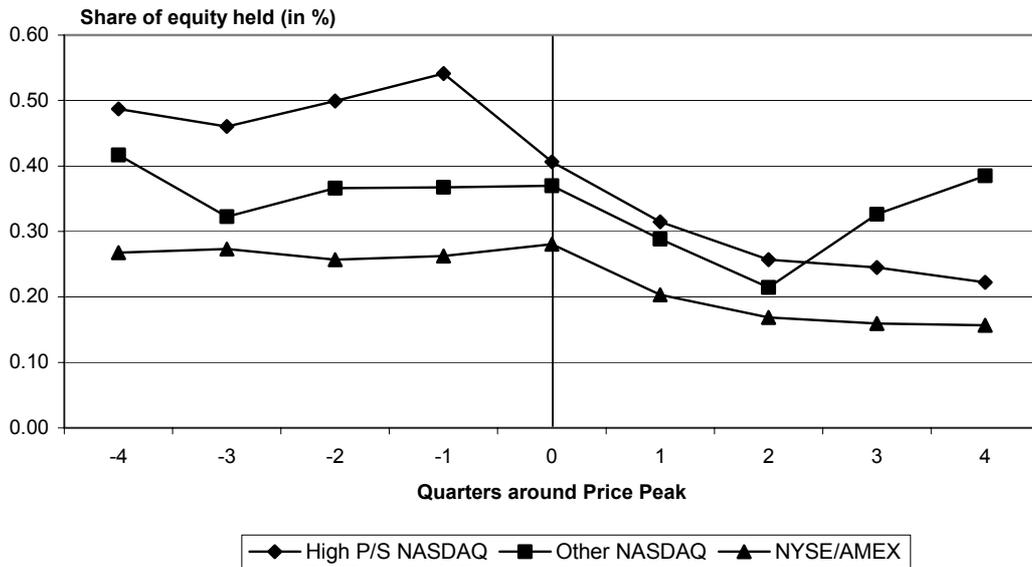


Fig. 5: Average share of outstanding equity held by hedge funds around price peaks of individual stocks. For each stock we construct a total return index from 1998 to 2000 from which we determine each stock's price peak during this period. Each quarter, we also calculate the proportion of outstanding shares that is held by hedge funds. For stocks with peaks in 1999 or 2000, we align these time series of holdings in event time (value-weighted), where the price peak is the event-time quarter 0. We then average hedge fund holdings in event time across all stocks in the sample. The figure presents these event-time averages for three different samples of stocks: Stocks in the high P/S quintile of the NASDAQ, other NASDAQ stocks, and NYSE/AMEX stocks.

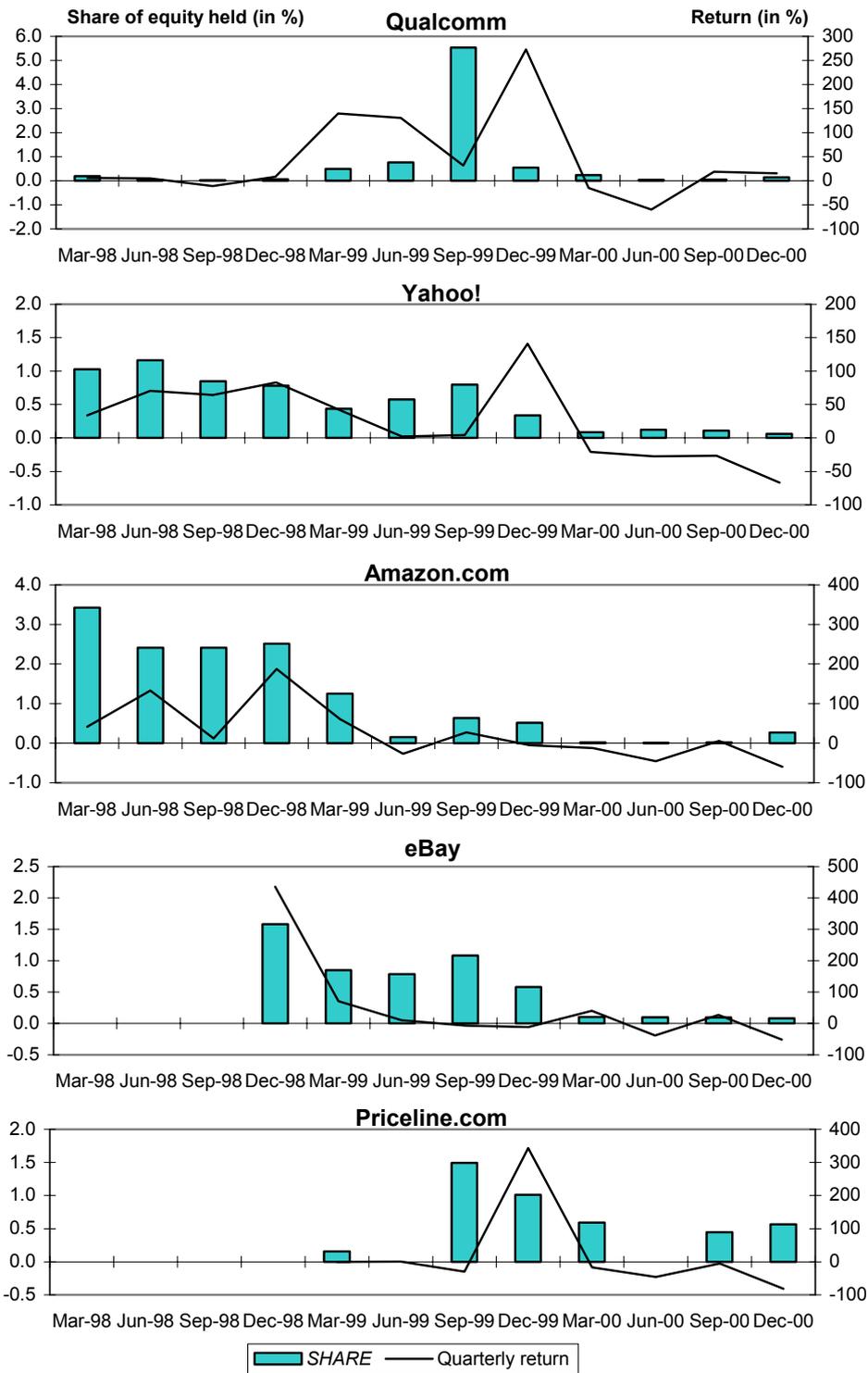


Fig. 6: Hedge fund holdings and quarterly returns for five individual internet stocks. The share of outstanding equity held by hedge funds at the end of each quarter is represented by the columns and reported in percent, and with the corresponding axis on the left. The lines plot returns within each quarter, with the corresponding axis on the right.

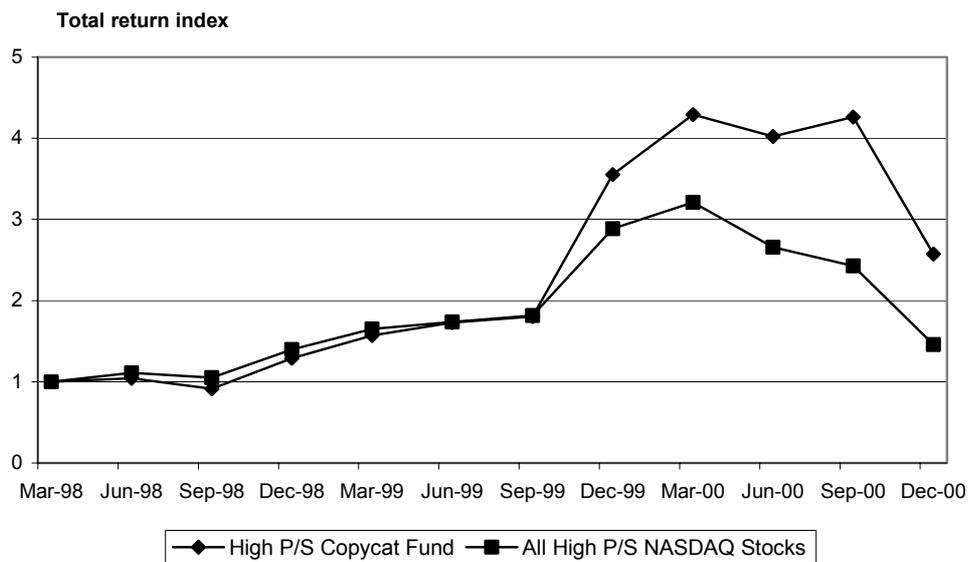


Fig. 7: Performance of a copycat fund that replicates hedge fund holdings in the NASDAQ high P/S segment. At the end of each quarter we form a portfolio that replicates aggregate hedge fund holdings in the NASDAQ high P/S segment as of that quarter-end. Stocks are held until the portfolio is rebalanced at the end of the next quarter. The figure shows the buy-and-hold return on this portfolio and on the value-weighted portfolio of all high P/S NASDAQ stocks.