Hedge fund holdings and stock market efficiency

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ABSTRACT

We examine the relation between changes in hedge fund equity holdings and measures of informational efficiency of stock prices derived from transactions data, and find that, on average, increased hedge fund ownership leads to significant improvements in the informational efficiency of stock prices. The contribution of hedge funds to price efficiency is greater than the contributions of other types of institutional investors, such as mutual funds or banks. However, stocks held by hedge funds experienced extreme declines in price efficiency during liquidity crises, most notably in the last quarter of 2008, and the declines were most severe in stocks held by hedge funds connected to Lehman Brothers and hedge funds using leverage.

Keywords: hedge funds, institutional investors, equity holdings, market efficiency.

JEL Classifications: G14, G23.

Hedge fund ownership of stocks has increased rapidly over the past decade, in particular prior to the outbreak of the Financial Crisis in 2008. At the end of 2007, hedge funds held about 10% of outstanding shares of the average firm listed on U.S. stock exchanges. Moreover, hedge fund trading accounts for at least one-third of the equity trading volume on NYSE according to the McKinsey Global Institute (2007). Hedge funds dominate the trading of certain stocks and are among the most important players in equity markets. Still, very little is known about the effects of hedge fund ownership on the informational efficiency of stock prices.

An increase in hedge fund stock ownership might improve or reduce stock market efficiency. On the one hand, hedge funds could make stock prices more informationally efficient by conducting research about the fundamental value of stocks and using short-term trading strategies to exploit mispricing. Indeed, academic researchers and practitioners have long regarded hedge funds as among the most rational arbitrageurs—sophisticated investors who quickly respond when prices deviate from fundamental values. For example, Alan Greenspan, the former chairman of the Federal Reserve System, remarked that "many of the things which [hedge funds] do … tend to refine the pricing system in the United States and elsewhere."[1] According to Brunnermeier and Nagel (2004), hedge funds are probably closer to the ideal of "rational arbitrageurs" than any other class of investors. Compared to the managers of mutual funds and other investment companies, hedge fund managers have contracts that provide them with stronger incentives and a higher degree of managerial discretion (e.g., Agarwal, Daniel, and Naik, 2009), allowing hedge fund managers to spot mispricing quickly and trade with greater flexibility. This view fits with the fact that hedge funds engage extensively in investment research, conduct statistical and event-driven arbitrage, and in many cases act as informed activist investors (e.g., Brav, Jiang, Partnoy, and Thomas, 2008).

[1] Testimony of Alan Greenspan before the House Committee on Banking and Financial Services (October 1st, 1998).

On the other hand, hedge funds' quantitative trading strategies and reliance on leverage could destabilize financial markets and reduce price efficiency. Hedge funds often employ quantitative models to identify stocks that are undervalued or overvalued. Stein (2009) argues that the elimination of arbitrage opportunities by sophisticated investors such as hedge funds is not necessarily associated with a reduction in non-fundamental volatility. If a large number of leveraged arbitrageurs adopt the same strategy, such as buying technology stocks or the stocks of firms with low values of accruals, the resulting overcrowding could create a fire sale effect in prices, inflicting losses on other traders, and generating increases in non-fundamental volatility. In fact, the "Quant Meltdown" of August 2007 documented by Khandani and Lo (2011) is a clear example of a crowded trade that led to the kind of fire sales and liquidity spirals theorized by Stein (2009).

In addition, many hedge funds leverage their investments, typically through short-term funding (e.g., Lo, 2008; Ang, Gorovyy, and Inwegen, 2011). This reliance on short-term funding leaves their portfolios exposed to funding shocks. If hedge funds' access to funding is impaired, as it was during the recent crisis, hedge funds could be forced to sell assets at fire sale prices. The forced selling imposed by lenders can be associated with near-term asset value deterioration and inefficient pricing (e.g., Brunnermeier and Pedersen, 2009; Khandani and Lo, 2011; Teo, 2011; Mitchell and Pulvino, 2012). Finally, hedge funds may decrease their market exposure or even withdraw from markets altogether when market liquidity is low, thus increasing non-fundamental volatility during liquidity crises (e.g., Cao, Chen, Liang, and Lo, 2013).

Understanding the role of hedge funds in securities markets is important for several reasons. First, because of hedge funds' increased involvement in public equity markets, many investors hold stocks that are owned and traded by hedge funds. These investors are favorably (adversely) affected by the higher (lower) price efficiency that results from hedge fund trading. According to Pagano (1989), risk-averse investors may even choose to desert stocks with high volatility unrelated to fundamentals. Further, hedge funds have recently come under increased regulatory scrutiny because of the

possibility that their trading may contribute to financial crises. It is therefore of interest to regulators whether higher hedge fund ownership makes stock prices more informative or, instead, increases pricing errors, especially during times of market stress. Finally, hedge funds' contribution to price efficiency matters because the information in stock prices guides investment decisions and therefore the allocation of economic resources and welfare (Tobin, 1969; Dow and Gorton, 1997). More efficient stock prices also improve investor welfare by facilitating hedging and risk sharing (Dow and Rahi, 2003).

To test the two competing hypotheses regarding how hedge funds affect market efficiency, we empirically examine the relation between changes in hedge fund ownership of stocks and the informational efficiency of prices. We derive three measures of informational efficiency from stocks' intraday trades and quotes: pricing error variance (PEV), return autocorrelations, and variance ratios. Our main measure (PEV) was proposed by Hasbrouck (1993), and uses statistical techniques to resolve the time series of security transactions prices into a random walk component and a residual stationary component (see Beveridge and Nelson, 1981). The random walk component is identified as the efficient price, and the residual component as the pricing error. PEV measures how closely actual transaction prices track a random walk. In addition to past returns, the conditioning information to estimate PEV includes volume and order flow data. PEV is therefore a more comprehensive measure of price efficiency than measures that rely on price data alone. The other two measures of price efficiency, return autocorrelations and variance ratios, are calculated from intraday stock returns. They capture patterns in stock returns that are inconsistent with efficient pricing, namely serial dependencies in quote midpoint returns and discrepancies between the variances of long-term and short-term returns.

Using comprehensive data on quarterly changes in hedge fund equity holdings between 2000 and 2012, we find that stocks bought by hedge funds subsequently increase in price efficiency compared with stocks sold by hedge funds in the same period. This finding supports the view that, on average, hedge funds operate as arbitrageurs and contribute to the informational efficiency of prices.

However, this effect was reversed during liquidity crises, most notably in the last quarter of 2008, when greater hedge fund ownership led to subsequent declines in price efficiency. The declines in price efficiency coincided with sharp increases in the TED spread (the difference between the 3-month U.S. dollar LIBOR rate and the 3-month T-bill rate), and were more severe for stocks held by hedge funds that use leverage. These findings support the hypothesis that the effect of hedge funds on market efficiency depends critically on the availability of funding.

We further analyze the changes in price efficiency around the bankruptcy of Lehman Brothers, and find that declines in price efficiency were most pronounced in stocks held by hedge funds using Lehman Brothers as their prime broker and stocks held by hedge funds using leverage. Lehman-connected hedge funds lost access to funding from their prime broker following Lehman's bankruptcy. Many of these funds also suffered severe losses due to their exposure to Lehman's London-based prime brokerage arm, forcing them to raise cash through asset sales. Our findings demonstrate that the price efficiency of stocks held by Lehman-connected hedge funds was severely reduced by these fire sales. We find similar evidence when we examine the changes in stock price efficiency during the 2007 Quant Meltdown. In particular, stocks held by leveraged hedge funds experienced greater declines in price efficiency following the quant meltdown than stocks held by other types of institutional investors. Taken together, the findings from the crisis episodes provide support for the theory of Brunnermeier and Pedersen (2009) and Mitchell and Pulvino (2012) that funding shocks may force hedge funds to de-lever by selling assets, temporarily causing an inefficient valuation of these assets.

We also compare hedge funds' effect on price efficiency with the effects of other institutional investors, such as mutual funds and banks. We find some evidence that higher ownership by banks and mutual funds is associated with efficiency gains in normal times and, in contrast to hedge fund ownership, also during liquidity crises. However, stock acquisitions by hedge funds improve informational efficiency in normal times significantly more than do acquisitions by banks or mutual funds. This finding supports the hypothesis that hedge funds add more to equity market quality than other

types of institutional investors. Moreover, changes in mutual fund and bank ownership do not significantly affect price efficiency after controlling for the accompanying changes in stock volatility, liquidity, and turnover. In contrast, the effect of hedge fund ownership on price efficiency remains positive and significant even after controlling for the attendant changes in volatility, liquidity, and turnover. This finding lends credence to the view that hedge funds, more than other institutional investors, impound information into stock prices, improving stock market efficiency.

Our paper contributes to the growing literature on hedge funds and their impact on financial markets. Several studies, including Fung and Hsieh (2000), Boyson, Stahel, and Stulz (2011), Billo, Getmansky, Lo, and Pelizzon (2012), and Brown, Goetzmann, Liang, and Schwarz (2012) consider the role of hedge funds in spreading financial crises. Boyson, Stahel, and Stulz (2011) examine hedge fund index return data and find evidence of contagion across hedge fund styles during liquidity crises. We contribute to this debate by showing that hedge funds' impact on equity market efficiency, though generally positive, can become negative during liquidity crises. Brunnermeier and Nagel (2004) and Griffin, Harris, Shu, and Topaloglu (2011) analyze hedge funds' holdings of technology stocks during the technology bubble of the late 1990s, and show that hedge funds sold off technology stocks before other investors when the bubble started to burst. Agarwal, Jiang, Tang, and Yang (2013) examine holdings for which hedge funds request confidential treatment from the SEC with a view to delaying their disclosure. They find that stocks in these holdings exhibit superior performance indicating that some hedge fund managers possess information not contained in contemporaneous stock prices. In this paper, we examine measures of price efficiency in the cross-section of stocks over an extended time period, and show that these measures generally improve when hedge funds increase their ownership stakes.

More broadly, our paper adds to the body of literature on the role of institutional investors in the stock market. Recent papers on this topic include Boehmer and Kelly (2009), Yan and Zhang (2009), Dasgupta, Prat, and Verardo (2011), Lewellen (2011), and Manconi, Massa, and Yasuda

(2012). We extend prior research by examining the roles played by specific types of institutions, such as mutual funds, hedge funds, and banks. Our results provide evidence that hedge funds contribute more to price efficiency than other types of institutional investors or individual investors.

The remainder of the paper is organized as follows. Section I presents summary statistics for several measures of informational efficiency; Section II presents data on hedge fund equity holdings and other ownership variables; Section III presents sample characteristics and control variables; Section IV analyzes the effect of hedge fund ownership on informational efficiency; and Section 5 offers concluding remarks.

I. Measures of informational efficiency of prices

Securities prices are said to be informationally efficient if they fully and correctly reflect all relevant information. Grossman and Stiglitz (1980) show that perfect efficiency is unlikely to hold in practice because arbitrage is costly and informed investors must be rewarded for gathering and processing information. This motivates the use of relative efficiency measures to compare the price efficiency of different securities against one another. We derive several measures of relative price efficiency from stocks' intraday trades and quotes. The measures are based on the assumption that efficient stock prices follow a random walk process, and assess how closely actual transactions prices track a random walk. We compute the measures from intraday returns because daily returns on active stocks have been found to be indistinguishable from a random walk (see, e.g., Chordia, Roll, and Subrahmanyam, 2005).

Our main measure of price efficiency is pricing error variance (PEV), first proposed by Hasbrouck (1993). PEV uses a random walk decomposition of the stock price to measure how closely the observed transaction prices conform to the random walk model. According to Hasbrouck (1993),

the observed transaction price (p_t) can be thought of as a sum of the efficient price (m_t), which follows a random walk process, and a residual component (s_t), termed the pricing error:

$$p_t = m_t + s_t. \tag{1}$$

The pricing error (s_t) follows a zero-mean covariance-stationary process, and its variance (PEV) is therefore a measure of its magnitude. PEV reflects the speed with which transaction prices adjust to new information. A higher PEV implies a slower convergence of transaction prices to the efficient price and therefore a lower informational efficiency of prices.

The estimation of PEV is based on the method introduced by Beveridge and Nelson (1981) to decompose a non-stationary time series into a random walk component and a stationary component. We follow the procedure suggested by Hasbrouck (1993) and employ a fifth order vector autoregressive (VAR) model of returns and three trade variables, including the trade sign, the signed trade volume, and the signed square root of the trade volume.[2] Pricing errors are identified a function of conditioning data on past returns, volume, and order flow. As shown by Hasbrouck (1993), the addition of the trade variables to the explanatory variable set strengthens the estimates of PEV.

We estimate the VAR coefficients monthly for each stock with 500 trades or more, and obtain monthly estimates of pricing error variance. Trades are matched with contemporaneous quotes (see Bessembinder, 2003), and the trade sign is determined using the Lee and Ready (1991) algorithm. Details about the estimation of PEV are provided in Appendix A. We refer to the natural logarithm of one plus the pricing error standard deviation multiplied by 100 as PEV. Boehmer and Kelly (2009) find that PEV is strongly related to the total intraday price variance. Therefore, we use the standard deviation of log transaction prices as a control variable in multivariate tests. We also divide the standard deviation of pricing errors by the standard deviation of log transaction prices, and use this ratio expressed in percent as the standardized PEV.

[2] The VAR estimates are not sensitive to using longer lag structures.

In addition to PEV, we compute two alternative measures of price efficiency: return autocorrelations and variance ratios. These measures rely solely on patterns in stock returns, using narrower information sets than PEV. Serially correlated returns are inconsistent with random walks, but Chordia, Roll, and Subrahmanyam (2005) show that many stocks have autocorrelated returns at 15- to 60-minute intervals. Similar to Chordia et al. (2005), we compute return autocorrelations from the midpoints of bid-ask spread quotes at non-overlapping 30-minute intervals. Our tests use the absolute value of quote midpoint return autocorrelations because high levels of midpoint return autocorrelations, both positive and negative, indicate relative inefficiency.

We also examine variance ratios as an alternative measure of relative price efficiency. An important property of a random walk process is that the variance of its increments must be proportional to the time interval over which the returns are sampled (e.g., Lo and MacKinlay, 1988). Many studies have exploited this property to construct empirical tests of price efficiency based on the ratios of long-term to short-term variance.[3] In line with these studies, we compute the following measure of departures from a random walk:

$$\left|1 - \frac{15\sigma_{30}^2}{30\sigma_{15}^2}\right|, \tag{2}$$

where σ^2_{15} and σ^2_{30} are the return variances measured over 15- and 30-minute intervals, respectively. This measure captures the absolute deviations of the ratio of long-term to short-term variance from one, which is the expected value of the ratio under the random walk hypothesis. Greater deviations of the variance ratio from one signal lower price efficiency. All efficiency measures are estimated at the monthly frequency using intraday data.

Panel A of Table I provides summary statistics for the efficiency measures. The means, medians, and standard deviations are first calculated across all sample stocks in each quarter, and the table

[3] See Ronen (1997) for a survey.

shows the time series averages of the cross-sectional measures for the entire period from 2000 to 2012 and for three sub-periods. The measure of PEV has an overall mean of 4.81 and a standard deviation of 0.52. PEV is greater in the first period (2000–2003) than in the later time periods, suggesting that price efficiency has increased over time, although PEV increased again during the 2008–2009 financial crisis and it peaked in September 2008. The mean of the standardized PEV is 3.32, and the means of the variance ratio and autocorrelation measures are 0.38 and 0.16, respectively.

II. Hedge fund stock holdings

Our analysis of the effects of hedge funds on price efficiency requires information on hedge fund stock ownership. Since information on hedge fund holdings is not available from standard databases, we hand-collect the data from several sources. We obtain quarterly institutional 13F holdings from Thomson Reuters, and go through a labor-intensive process to distinguish hedge fund ownership from ownership by investment advisers and other types of institutional money managers. All institutional investment managers—including hedge fund management companies—that have investment discretion over $100 million or more are required to disclose their quarter-end holdings of stocks on Form 13F. The mandatory disclosure of holdings excludes positions smaller than $200,000 in market value, short positions, derivatives, and certain confidential holdings that may be disclosed with a delay through amendments as discussed by Agarwal et al. (2013).[4]

To identify hedge fund managers among 13F filers, we collect lists of hedge fund management companies from six hedge fund databases, including TASS, HFR, CISDM, Morningstar, Barclay Hedge, and Bloomberg, and match them with company names from 13F reports. To make the classi-

[4] We address the exclusion of short positions from 13F reporting by collecting data on the aggregate short interest for each stock. The exclusion of derivatives and certain confidential holdings may bias the results against finding support for the hypothesis that hedge funds contribute to market efficiency.

fication as comprehensive as possible, we look up in the Bloomberg/BusinessWeek private equity database the names of all private companies that file form 13F to find out whether they are hedge funds. After matching, we cross-check all companies that are registered as independent investment advisers to confirm that their main line of business is managing hedge funds.

Registration as an investment adviser is a pre-condition for managing portfolios for non-hedge fund clients, such as mutual funds or pension funds. We find that most of the sample hedge fund management companies are registered as investment advisers, and manually check their SEC registration documents (form ADV) to classify them as hedge fund managers or non-hedge fund managers. Companies are classified as hedge fund managers if they indicate in the ADV form that more than 50% of their customers are hedge funds or high net worth individuals, and that they charge performance-based fees. Based on these criteria, we reclassify about one-third of the matched management companies as non-hedge fund investment advisers, including major investment banks and their asset management subsidiaries. These companies do not belong in the sample of hedge fund managers because hedge fund assets constitute only a fraction of their reported holdings.

In total, we classify 1,594 filers of 13F reports between 2000 and 2012 as hedge fund management firms. The number of hedge funds under management of these firms is about three times larger because the typical hedge fund firm manages three funds on average. We aggregate hedge fund holdings for each stock in each quarter and measure hedge fund ownership by the fraction of outstanding shares held by hedge funds.

On average over the sample period, hedge funds own 7% of outstanding shares for the typical firm listed on NYSE, AMEX, or NASDAQ. However, hedge fund stock ownership varies considerably in the cross-section of stocks and over time. The 90th percentile of hedge fund ownership is 17%, suggesting that hedge funds own a large fraction of equity for a non-negligible number of firms. Figure 1 plots the mean percentage of shares held by hedge funds over time, and reveals a significant increase in hedge fund stock ownership from 2000:Q1 until 2012:Q4. On average, hedge fund holdings were

less than 3% of the outstanding shares at the beginning of the sample period in 2000.[5] Hedge funds hold nearly 11% of the sample firm's equity in the second quarter of 2008, before holdings fall back below 8% in the second quarter of 2009 as a result of the financial crisis. Hedge fund holdings recover again after the crisis and average 10% of outstanding shares at the end of 2012.

In addition to hedge fund holdings, we collect holdings data for other types of institutional investors. We classify non-hedge fund investors into three categories: (1) banks and insurance companies, (2) mutual funds, and (3) others. The category "others" includes non-hedge fund investment advisers, foundations, endowments, and private pension funds. The classifications are based on the type codes available from Thomson Financial. As Panel B in Table I reports, mutual fund holdings are the most important, accounting for 32% of outstanding shares on average. Commercial banks and insurance companies hold 14% of outstanding shares on average, and others hold 12%. With the exception of bank holdings, all types of institutional holdings exhibit an upward trend over the entire sample period from 2000 to 2012. In addition to the percentage of shares held by different types of institutional investors, we also gather data on the total number of institutional shareholders. Holding constant the level of institutional ownership, stocks with a greater number of investors have a more dispersed ownership. The average number of institutional investors for sample stocks is 175.

Our measures of price efficiency are computed monthly, while institutional holdings are observed at the quarterly frequency. We therefore conduct the analysis of price efficiency at the quarterly frequency, and match efficiency measures from the first month of quarter q with institutional holdings from quarter $q–1$. Thus, efficiency is measured from the report date until the end of the subsequent month. This method of aligning the data ensures that efficiency is measured right after the report date

[5] The sample starts in 2000 because hedge fund holdings were very small for most stocks in earlier years. For example, hedge fund holdings averaged 2.2% of outstanding shares from 1995 to 1999.

for institutional holdings. As a robustness test, we also measure price efficiency by the average of the monthly efficiency measures in quarter *q*.

III. Sample characteristics and control variables

Our sample is comprised of common stocks listed on the NYSE, AMEX, or NASDAQ exchanges during the January 2000 through December 2012 time period. The data are from the intersection of CRSP, Compustat, Thomson Financial, Bloomberg, and TAQ intraday databases. We use the following sample selection criteria to obtain reliable estimates of the efficiency measures: (1) stocks with fewer than 500 trades per month are excluded; (2) stocks with share prices less than $5 at the end of the previous month are excluded; (3) companies incorporated outside the U.S., closed-end funds, and REITs are excluded. The final sample consists of 151,580 stock/quarter observations between 2000 and 2012, and the average number of stocks per quarter is 2,915. Most of our tests use data on changes in efficiency and institutional ownership between two consecutive quarters. This requirement limits the sample to 136,259 observations over 51 quarters (2000:Q2 to 2012:Q4), and the average number of stocks per quarter is 2,671.

We control for a number of variables that may affect price efficiency, including the short interest ratio, firm characteristics, stock volatility, and liquidity. Previous studies find that short selling can increase the informational efficiency of prices (e.g. Saffi and Sigurdsson, 2010; Boehmer and Wu, 2013). Brokerage firms are required to report their total short positions as of settlement on the 15th of each month. We obtain the data on short positions from Bloomberg and calculate monthly short interest ratios by dividing short interest by total shares outstanding from CRSP. Short interest ratios are measured in the same month as institutional holdings.

The data on firm characteristics, including total assets, book-to-market ratios, and leverage are obtained from Compustat quarterly files. Firm characteristics are measured at quarter end, as of the

same date as institutional holdings. The book-to-market ratio is the book value of shareholders' equity divided by the market value of equity. Leverage is measured as the sum of current liabilities and long-term debt over total book assets.

Volatility and liquidity are related but distinct concepts from informational efficiency. Volatility can be caused by either noise or uncertainty about the fundamental value of securities. Liquidity refers to the ability to buy and sell securities quickly and cheaply without affecting the market price, whereas informational efficiency refers to the speed with which prices reflect relevant information. Because volatile and illiquid securities are expensive to trade, their prices typically incorporate new information more slowly. Thus, when testing for the effects of hedge fund ownership on price efficiency, we control for contemporaneous changes in volatility and liquidity.

We measure intraday volatility by the standard deviation of log transaction prices, and calculate two liquidity measures from intraday transactions: the effective bid-ask spread and turnover. The effective bid-ask spread is computed as two times the absolute value of the difference between the actual transaction price and the midpoint of the bid-ask point, divided by the quote midpoint. Turnover is the ratio of the annualized trading volume to the number of outstanding shares. We compute all measures on a monthly basis, contemporaneously with measures of price efficiency.

Panel C of Table I presents summary statistics for the control variables. The mean short interest ratio is 5% of shares outstanding. The average firm in the sample has total assets of $11.7 billion, a book-to-market equity ratio of 0.57, and a leverage ratio of 0.21. On average, the standard deviation of log transaction prices is 1.42, the annualized turnover ratio for shares is 2.74, and the effective percentage bid-ask spread is 0.31% for sample stocks.

IV. Empirical analysis

A. The Characteristics of Hedge Funds' Equity Holdings

Before examining the effects of hedge fund ownership on market efficiency, we provide a more detailed analysis of hedge funds' equity holdings. Table II reports the summary statistics for our sample stocks sorted into terciles based on the percentage of outstanding shares held by hedge funds in each quarter. There is a large dispersion in hedge fund ownership among the three portfolios. On average, hedge funds hold 1% of outstanding shares in the low hedge fund ownership portfolio, 5% in the medium hedge fund ownership portfolio, and 14% in the high hedge fund ownership portfolio.

Panel A of Table II reports the efficiency measures for the portfolios sorted by hedge fund ownership. The measures reveal that hedge funds tend to hold stocks that are priced relatively inefficiently. The average PEV in the high hedge fund ownership portfolio is 5.04, which is significantly greater than the average PEV of 4.72 observed in the low hedge fund ownership portfolio. Stocks in the high hedge fund ownership portfolio also have greater variance ratios and higher autocorrelations than stocks in the low hedge fund ownership portfolio, suggesting that hedge funds have a preference for less efficiently priced stocks.

Panel B reports other characteristics of stocks in the three portfolios and reveals that stocks held by hedge funds have greater short interest ratios than stocks that are not held by hedge funds. The companies in which hedge funds invest are also significantly smaller, tend to use more leverage, and are more likely to be listed on NASDAQ. These stocks are more volatile, but tend to have relatively high turnover and low bid-ask spreads. Stocks in the high hedge fund ownership portfolio also have a greater percentage of shares held by non-hedge funds than stocks in the low hedge fund ownership portfolio, although they have a lower percentage of shares held by non-hedge fund than stocks in the medium hedge fund ownership portfolio. Overall, the statistics reported in Table II reveal that hedge funds have a preference for small stocks that are inefficiently priced but are relatively liquid, exactly

what we would expect from rational arbitrageurs balancing arbitrage opportunities against transactions costs.

B. Changes in hedge fund holdings and price efficiency

B.1. Portfolio-level analysis

As shown in the previous section, hedge funds have a preference for stocks with certain characteristics that are associated with a low degree of price efficiency. Thus, to identify the causal effect of hedge fund ownership on price efficiency, we examine how the price efficiency of stocks changes subsequent to increases and decrease in hedge fund ownership. Our analysis of the effects of hedge fund ownership on price efficiency starts with tests at the portfolio level. We sort stocks into three portfolios based on the changes in hedge fund holdings from quarter $q-1$ to quarter q and examine the changes in price efficiency for each portfolio from quarter q to quarter $q+1$. Portfolio "Buy" includes stocks for which hedge funds increase their holdings by more than 1% of shares outstanding in quarter q. Portfolio "Sell" includes stocks for which hedge funds decrease their holdings by more than 1% of shares outstanding in quarter q. Portfolio "No Change" includes all other stocks, about half of the sample on average. We use 1% of outstanding shares as the threshold for a significant change in ownership for consistency with earlier studies (e.g., Chen, Jegadeesh, Wermers, 2000; Cohen and Schmidt, 2009), but the results are essentially unchanged if 2% or 3% is used as the threshold.

Figure 2 depicts the number of stocks in the "Buy" and "Sell" portfolio from 2000 to 2012, and the difference between the number of stocks in the two portfolios. The figure reveals that hedge funds were net buyers of stocks in most quarters until the beginning of 2007. Hedge funds became net sellers of stocks in the third quarter of 2007, and in particular in the third and the fourth quarter of 2008.

Stocks with an increased hedge fund ownership become closely followed by hedge funds, and they are more likely to be traded again by hedge funds over the subsequent quarter than stocks with a

decreased or unchanged hedge fund ownership. As shown in the second part of Table III, stocks in the "Buy" hedge fund portfolio in quarter *q* are significantly more likely to be in either the "Buy" or the "Sell" hedge fund portfolio in quarter *q+1* than stocks in the other portfolios, suggesting that hedge funds research the fundamentals of these stocks, and buy more shares or sell their holdings if prices converge to the estimated fundamental value.

We examine how the informational efficiency of prices changes for stocks in the portfolios sorted by changes in hedge fund ownership. Price efficiency is measured in the first month of quarter *q+1*, i.e., immediately after the holdings report for quarter *q*. Changes in price efficiency are calculated between the first month of quarter *q* and *q+1*.[6] Since our focus is on cross-sectional variations in price efficiency rather than on time-series variations, we subtract the periodic average from the changes in price efficiency in each quarter.

Table III reports the average change in informational efficiency for stocks in the "Buy" and "Sell" portfolios from 2000 to 2012. The table reveals that stocks bought by hedge funds subsequently experience improvements in price efficiency compared to stocks sold by hedge funds during the same period (and compared to stocks with no change in hedge fund ownership). For example, PEV for stocks bought by hedge funds decreases by 0.109, on average, compared to the PEV for stocks sold by hedge funds. The difference between the changes in PEV of the "Buy" and "Sell" portfolios is statistically significant and meaningful at 0.21 standard deviations of the PEV measure (0.109/0.52).

The standardized PEV, variance ratios, and return autocorrelations all decrease after hedge funds increase their ownership by 1% or more. We use the difference-in-differences approach to compare the changes in price efficiency of the "Buy" and "Sell" portfolios. The differences are negative

[6] For example, institutional holdings for 2008:Q1 are reported as of March 31, 2008. The informational efficiency for 2008:Q2 is measured in April 2008, immediately after the report date for 2008:Q1, and the change in efficiency is calculated from January 2008. As a robustness check we also average the monthly measures of efficiency over the entire quarter (April, May, and June), and compare them with the average of the efficiency measures in the previous quarter (January, February, and March).

and significant at the 1% level for all of the liquidity measures, indicating that changes in hedge fund holdings are followed by increases in price efficiency. These results provide support for the hypothesis that greater hedge fund ownership leads to more efficient pricing of stocks.

Table IV extends the analysis of the changes in price efficiency to firms of different sizes. We sort stocks into quartiles based on their market capitalization in each quarter, and then on changes in hedge fund holdings within each size quartile. The results indicate that the effect of hedge fund holdings on price efficiency depends on firm size. Hedge fund buying and selling has the greatest effect on the informational efficiency of small and medium-capitalization stocks, and has the smallest effect on large capitalization stocks. For example, the average difference-in-differences of PEV between small stocks purchased and sold by hedge funds is -0.157 (0.30 standard deviations), significant at the 1% level, but it is only -0.059 for large stocks (0.11 standard deviations), significant at the 10% level.

We further explore how the changes in holdings of institutions other than hedge funds affect price efficiency. Table V reports the changes in informational efficiency for stocks sorted into "Buy" and "Sell" portfolios according to changes in mutual fund holdings. The table reveals that increases in mutual fund ownership are on average also associated with improvements in price efficiency as measured by PEV. However, changes in mutual fund holdings have a smaller effect on price efficiency than changes in hedge fund holdings. The difference-in-differences in PEV is only -0.030 (0.06 standard deviations) when stocks are sorted according to change in mutual fund ownership, compared to 0.109 (0.21 standard deviations) when stocks are sorted according to changes in hedge fund ownership. Besides, the effect of mutual fund ownership is not significant at the 5% level according to the other measures of efficiency. In the next section, we conduct a firm-level analysis and examine in greater detail the differences between the effects of different types of institutional investors on price efficiency.

B.2. Firm-level analysis

The analysis at the portfolio level reveals that increases in hedge fund ownership are associated with improvements in the informational efficiency of prices. Next, we conduct a firm-level analysis to compare the effect of hedge funds on informational efficiency with the effects of other types of institutional investors. The firm-level analysis also allows us to control for changes in stock characteristics. In each quarter q, we estimate the following cross-sectional regression:

$$\Delta IE_{i,q} = \gamma_0 + \gamma_1{}'\Delta IO_{i,q-1} + \gamma_2{}'\Delta CHAR_{i,q-1} + \gamma_3{}'\Delta V\&L_{i,q} + \gamma_4 IE_{i,q-1} + \varepsilon_{i,q,} \quad (3)$$

where $IE_{i,q}$ is the informational efficiency of stock i in the first month of quarter q, and $\Delta IE_{i,q}$ is the change in informational efficiency between the first months of quarters $q–1$ and q.[7] Vector $IO_{i,q-1}$ contains institutional ownership variables for stock i, including the percentage of shares held by banks and insurance companies, mutual funds, hedge funds, and the log of the total number of institutional investors holding shares at the end of $q–1$. The omitted ownership type is individual ownership, which is the benchmark against which the effects of institutional ownership are measured. $CHAR_{i,q-1}$ is a vector of firm characteristics, including total assets, book-to-market ratio, and leverage, and short interest ratio, measured at the end of quarter $q–1$. In some specifications, we also control for contemporaneous changes in volatility and liquidity ($V\&L_{i,q}$) to examine whether the changes in price efficiency occur because institutions impound information more quickly into stock prices or if they simply reflect improved liquidity. $V\&L_{i,q}$ is a vector containing contemporaneous changes in volatility and liquidity, measured in the same month as informational efficiency. All variables are expressed as changes from the previous quarter.

[7] As a robustness check, we also measure the informational efficiency in quarter q as the average of informational efficiency measures in the first, second, and third month of quarter q.

In addition, the regression includes the lagged level of the dependent variable to account for a possible mean reversion of the efficiency measures. Inferences are conducted from the time series of coefficient estimates using the Fama-MacBeth (1973) methodology with heteroskedasticity and auto-correlation robust standard errors. Alternatively, we estimate pooled regressions with time fixed effects and standard errors clustered by firm and quarter.

Column (1) in Table VI presents estimates from cross-sectional regressions of changes in informational efficiency on changes in institutional ownership. The estimates reveal that changes in hedge fund holdings have a significant negative effect on PEV in the cross-section even after controlling for the holdings of other types of institutional investors. The coefficient estimate for changes in hedge fund holdings is -2.25, significant at the 1% level. Thus, a one standard deviation increase in hedge fund ownership (an increase by 4% of shares outstanding) decreases PEV by 0.17 standard deviations (2.25*0.04/0.52). The cross-sectional coefficient estimate is negative in 49 out of 51 quarters, and it is negative and statistically significant in 44 out of 51 quarters. The regression estimates further show that increases in the stock holdings of other types of institutional investors, including banks and insurance companies, mutual funds, and others also lower PEV. The coefficients for all types of institutional ownership are measured relative to individual ownership—the omitted category.

Non-hedge fund institutional investors have a smaller marginal effect on PEV than hedge funds. For example, a one standard deviation increase in mutual fund ownership (an increase by 6% of shares outstanding) decreases PEV by 0.05 standard deviations (0.46*0.06/0.52). Panel B of Table VI presents *F*-tests of the null hypothesis that changes in hedge fund holdings have the same effect on PEV as changes in the holdings of other financial institutions. The null hypothesis is rejected at the 1% level for all institutional types. Another interesting result emerging from Panel A in Table VI is that increases in the number of institutional stock holders lower PEV (after controlling for the amount of institutional holdings). This finding is consistent with the hypothesis that a greater number of institutional investors leads to improvements in the informational environment of the firm.

The regression in the second column of Table VI includes short interest, firm size, book-to-market equity, and leverage as explanatory variables. Changes in hedge fund ownership continue to have a significant negative effect on PEV after controlling for these variables, but the effects of bank and insurance company holdings and the holdings of other institutions become insignificant. Changes in PEV also remain negatively related to changes in mutual fund holdings, but the coefficient is small and only significant at the 10% level. The estimates further show that an increase in short interest ratios is associated with a decrease in PEV, which is consistent with prior findings that short selling improves informational efficiency (e.g., Saffi and Sigurdsson, 2010; Boehmer and Wu, 2013).

Finally, column (3) in Table VI includes contemporaneous changes in intraday volatility, turnover, and bid-asks spreads. Including volatility and liquidity measures improves the fit of the model considerably, and the R-squared is increased from 0.11 to 0.32. The estimates in column (3) show that lower price volatility, higher turnover, and lower bid-ask spreads are all associated with significant decreases in PEV. This finding makes sense since high price volatility is partially the result of inefficient pricing, and greater stock liquidity lowers the costs of arbitrage, which in turn leads to greater price efficiency. The regression in column (3) may therefore underestimate the effect that institutional ownership has on price efficiency. Nonetheless, the effect of hedge fund ownership on PEV remains negative and significant at the 1% level, indicating that hedge fund ownership improves price efficiency even after accounting for the associated changes in volatility and liquidity.

In contrast, changes in the holdings of banks and insurance companies, mutual funds, or other financial institutions do not significantly affect PEV after accounting for changes in volatility and liquidity. These results suggest that mutual fund and bank ownership increase price efficiency mostly because they reduce volatility and improve liquidity, whereas hedge fund ownership has an additional effect on price efficiency that is unrelated to its effect on volatility and liquidity. The additional effect

of hedge fund ownership is consistent with the view that hedge funds improve the informational efficiency of prices by gathering information about the value of assets and trading actively when prices move away from fundamental values.

Figure 3 shows the time series of the estimated effect of hedge fund ownership on price efficiency from the regressions of quarterly changes in pricing error variance on lagged changes in institutional holdings in column (1) of Table VI. For comparison, the figure also plots the TED spread, which is a measure of market-wide funding conditions. As the figure shows, the effect of hedge fund ownership on PEV is negative in 49 out of the 51 quarters, and it is negative and significant in 44 quarters, suggesting that hedge fund ownership typically improves the informational efficiency of stock prices. However, the effect of hedge fund ownership on PEV becomes positive in the fourth quarter of 2008 and in the second quarter of 2000 when the dot-com bubble burst. Interestingly, the periods when hedge fund ownership has a positive effect on PEV coincide with high levels of the TED spread, in particular during the recent financial crisis.[8] This finding suggests that the effect of hedge fund ownership on price efficiency depends on funding liquidity.

C. Hedge fund leverage and liquidity crises

Figure 3 suggests that hedge fund ownership does not improve price efficiency in times of market stress, and may even lower price efficiency during liquidity crises. We examine next whether the differential effect of hedge funds on price efficiency during liquidity crises is related to hedge funds' use of leverage. Many hedge funds leverage their investments, typically through short-term funding, which could lead to de-leveraging in a crisis when funding becomes scarce. The selling pressure caused by de-leveraging could lower the price efficiency of stocks held by leveraged hedge funds. On the contrary, some hedge funds do not employ leverage, and limit their investments to investors'

[8] Other measures of market-wide funding liquidity, such as the spread between 3-month LIBOR and overnight index swap rates (LIBOR-OIS spread), typically increase in the same quarters.

capital. Even these funds could be forced to sell securities in a crisis to meet investor redemptions. However, the selling pressure caused by funds that invest only their investors' capital would be smaller than that caused by de-leveraging. We therefore hypothesize that ownership by the hedge funds that use leverage should have a greater adverse impact on price efficiency during liquidity crises than ownership by hedge funds that don't use leverage and ownership by other types of institutions.[9]

We proceed to separate the stock holdings of leveraged hedge funds from other hedge funds to test whether the changes in price efficiency during liquidity crises are related to ownership by leveraged hedge funds. A complicating factor is that holdings are reported at the hedge fund company level, whereas leverage is a characteristic of individual hedge funds. We therefore collect fund-level information on the use of leverage from several hedge fund databases, including TASS, HFR, CISDM, Barclay Hedge, and Morningstar, and aggregate the information to the management company level.

Specifically, at the end of each quarter, we identify in the databases unique names of all live, equity-oriented hedge funds, and obtain information on their reported use of leverage. We don't count hedge funds that pursue other strategies including fixed-income, macro, commodity, currency, emerging market, and fund-of-fund strategies because these funds do not typically hold U.S. stocks. For each management company, we then compute the percentage of AUM of its equity-oriented funds that use leverage, and classify a management company as leveraged if the assets of funds that use leverage are greater than the assets of funds that do not use leverage. As an alternative measure of leveraged holdings, we also count the number of leveraged funds under management by each company in each calendar quarter, and classify a management company as leveraged if the number of leveraged funds exceeds the number of funds that report not to use leverage. We discuss below the tests using the asset-weighted leverage and note that the equal-weighted measure of leverage gives similar results.

[9] Even hedge funds that don't use leverage could be forced into fire sales by investors' redemptions.

Based on the asset-weighted leverage, we classify 33% of hedge fund firms as leveraged and 27% as unleveraged in a given period. The leveraged hedge fund companies on average hold 2.8% of the outstanding shares for sample stocks, whereas the unleveraged hedge fund companies hold 2.0% of the outstanding shares. Companies that cannot be accurately classified—either because they cannot be matched to a hedge fund database, or because they do not report leverage—hold an additional 2.2% of the outstanding shares over the sample period 2000–2012. Figure 4 reports the holdings of leveraged and unleveraged hedge fund firms in each quarter. The figure shows that leveraged hedge fund holdings have increased at a faster pace than unleveraged hedge fund holdings in the years leading to the financial crisis of 2007–2009, and they fell more sharply during the third and fourth quarter of 2008. The sharp fall in leveraged hedge fund holdings during the crisis is consistent with the hypothesis that hedge fund de-leveraging led to asset fire sales during the recent crisis.

In Table VII, we present the estimates from panel regressions of changes in PEV on changes in hedge fund holdings in normal times and during liquidity crises. Liquidity crises are defined as quarters when the average spread between the 3-month U.S. dollar LIBOR rate and the 3-month T-bill rate (TED spread) exceeds 1.5%. There are two such quarters between 2000 and 2012, spanning less than 5% of the sample period (51 quarters), namely 2008:Q2 and 2008:Q4.[10] Hedge fund holdings are divided according to use of leverage: Leveraged hedge fund holdings are included as a separate variable (*Leveraged HF hldg.*), and the unleveraged hedge fund holdings are combined with the unclassified hedge fund holdings in a variable called *Other HF hldg.* The regressions in Table VII are estimated with time fixed effects, and standard errors are clustered by firm and by quarter (see, Petersen, 2009).

[10] The results are identical if liquidity crises are defined as peaks in the 3-month LIBOR-OIS spread instead of the TED spread.

We note that the coefficient and standard error estimates from panel regressions are similar in magnitude to those of cross-sectional regressions using the Fama-MacBeth methodology with Newey-West standard errors.

Column (1) of Table VII shows the results for the entire sample period 2000–2012, without conditioning on liquidity crises. Both leveraged and other hedge fund holdings are significantly negatively associated with PEV. Thus, on average across the entire sample period, both leveraged and other hedge funds improve price efficiency. Columns (2) to (4) of Table VII report the estimates from regressions that include the interaction terms between institutional ownership and liquidity crises. These estimates reveal a striking difference between the effects of hedge fund ownership on price efficiency in normal times and during liquidity crises. If there is no liquidity crisis, hedge fund ownership significantly contributes to price efficiency regardless of hedge fund leverage. However, the effect of leveraged hedge fund ownership changes sign during liquidity crises, indicating that hedge fund ownership does not improve price efficacy during liquidity crises if the hedge funds use leverage. The interaction of leveraged hedge fund ownership with liquidity crises is significant positive in column (2), and effect of leveraged hedge fund ownership is positive and marginally significant (4.57 – 1.60 = 2.97, F-statistic = 2.92) conditional on a liquidity crisis. In contrast, the effect of other hedge fund ownership on liquidity risk is not significant conditional on a liquidity crisis (1.32 – 1.28 = 0.04, F-statistic = 0.01). Of note, mutual fund and bank ownership is associated with significantly greater reductions in PEV during liquidity crises than in normal times. These conclusions are further strengthened by controlling for changes in short interest, firm characteristics, and liquidity as shown in columns (3) and (4) of Table VII.

Panel B of Table VII provides tests for differences between the effects of leveraged hedge funds and other types of financial institutions on PEV. Based on the estimates in column (1) of Panel A, the tests reported in Panel B do not reject the hypothesis that, on average over the entire sample period, the effect of leveraged hedge fund ownership on PEV differs from the effect of other hedge

fund ownership. The tests in Panel B (based on the estimates in column (2) of Panel A) further show that in normal times, there is no significant difference between the effects of leveraged and other hedge funds on PEV. Both types of hedge fund ownership significantly reduce PEV if there is no liquidity crisis. In contrast, conditional on a liquidity crisis, leveraged hedge fund ownership increases PEV significantly more than ownership of other hedge funds, mutual funds, banks, or other types of institutional investors. The following sections examine several crisis periods in an event-study framework to provide additional insights into hedge funds' impact on price efficiency during crises.

D. Evidence from the Lehman bankruptcy

The Lehman bankruptcy on September 15, 2008 provides a unique setting to identify the effect of hedge fund ownership on price efficiency in a liquidity crisis because Lehman's failure caused liquidity problems for hedge funds that used Lehman as their prime broker and led to an increase in the failure rate of these funds (see Aragon and Strahan, 2012). Lehman-connected hedge funds not only lost access to financing from their prime broker, but many also suffered large losses due to their exposure to Lehman's London-based prime brokerage arm. The stocks held by Lehman Bothers' hedge fund customers were frequently subject to fire sales as hedge funds sought to unwind their positions to raise cash. We conduct an event study and examine whether the price efficiency of these stocks was adversely affected by Lehman's demise.

Lehman's bankruptcy date marks a large liquidity shock around which we examine changes in price efficiency. We compute the changes in stock price efficiency between the pre-crisis period August 1–August 31 and the crisis period September 15–October 15, skipping two weeks between the pre- and the crisis period. We then use data on stock ownership by Lehman-connected hedge funds as an instrument for fire sales, and examine whether the changes in stock price efficiency following Lehman's bankruptcy depend on the amount of stock ownership by hedge funds that used Lehman brothers as their prime broker. Institutional holdings are measured in June 2008, which is the last 13F report

date before the onset on the crisis. Aragon and Strahan (2012) provide a detailed description of the data on Lehman-connected funds.[11]

Figure 5 reports the percentage changes in PEV following Lehman's bankruptcy for stocks with different levels of ownership by Lehman-connected hedge funds. We note that Lehman-connected hedge funds held more that 1% of the outstanding shares for about one-fifth of sample stocks, and they held more than 5% for about one-fifteenth of sample stocks. PEV increased in the aftermath of Lehman's bankruptcy for all stocks regardless of their ownership. However, Figure 5 suggests that the increase in PEV was greater for stocks held by Lehman-connected hedge funds. While PEV increased by 130% for stocks with zero holdings by hedge funds connected to Lehman, it increased by almost 190% for stocks with 5% or more of the outstanding shares held by hedge funds connected to Lehman.

To test the hypothesis that the price efficiency of stocks held by Lehman-connected hedge funds was adversely affected by Lehman's bankruptcy, we estimate the following cross-sectional regression:

$$\Delta IE_{i,t} = \gamma_0 + \gamma_1 LEH_{i,t-1} + \gamma_2{}' IO_{i,t-1} + \gamma_3{}' CHAR_{i,t-1} + \gamma_4{}' \Delta V\&L_{i,t} + \gamma_5 IE_{i,t-1} + \varepsilon_{i,t,} \quad (4)$$

where $\Delta IE_{i,t}$ is the change in informational efficiency of stock i between the pre-crisis and the crisis period. $LEH_{i,\,t-1}$ is the fraction of shares in stock i held by hedge funds that used Lehman Brothers as their prime broker. Vector $IO_{i,t-1}$ contains institutional holdings of other institutional investors, including non-Lehman hedge funds, measured in June 2008. We use levels of institutional holdings rather than changes as explanatory variables for the event study because levels better reflect the amount of shares that institutions could be forced to sell as a result of the bankruptcy event. The other explanatory variables remain the same as in equation (3), except the characteristics (*CHAR*) are measured in levels rather than as changes.

[11] We thank Geroge Aragon and Philip Strahan for sharing their data on holdings of Lehman-connected funds.

Table VIII reports the regression estimates using changes in PEV as the dependent variable. Consistent with the estimates from the full period 2000–2012, most types of institutional holdings have a negative effect on PEV following the Lehman Brothers bankruptcy. In contrast, hedge fund holdings are positively associated with changes in PEV following Lehman's bankruptcy, showing that hedge fund trading had an adverse effect on price efficiency during the Lehman crisis. Most interestingly, equity holdings by Lehman-connected hedge funds have a significantly greater effect on PEV than holdings by non-Lehman connected hedge funds as shown by the tests in Panel B of Table VIII (see columns 1 and 2). These results show that the price efficiency of stocks held by Lehman-connected hedge funds was more negatively affected by Lehman's demise than the price efficiency of stocks held by other hedge funds. The difference between the stocks held by Lehman-connected hedge funds and other hedge funds becomes insignificant in column (3) after we control for simultaneous changes in liquidity, which supports the conclusion that both the liquidity and the efficiency of stocks held by Lehman-connected hedge funds were adversely affected by Lehman's bankruptcy.

We further analyze whether hedge fund leverage played a role in propagating the shocks to price efficiency following the failure of Lehman Brothers. Using the asset-weighted leverage to classify hedge fund companies, we identify 288 leveraged companies and 219 unleveraged companies as of June 2008. The leveraged hedge fund companies hold 4.2% of the outstanding shares for the average sample stock in June 2008, whereas the unleveraged hedge fund companies hold about 2.8% of the outstanding shares. Companies that cannot be accurately classified—either because they cannot be matched to a hedge fund database, or because they do not report leverage—hold an additional 3.9% of the outstanding shares. We add the unclassified holdings to the unleveraged holdings.

Table IX reports the results using the leveraged hedge fund holdings as an explanatory variable for changes in PEV following Lehman's bankruptcy. The regression model is the same as that in Eq. (4), except hedge fund holdings are classified according to leverage rather than Lehman ties. Leveraged hedge fund ownership is significantly related to increases in PEV (declines in price efficiency) after

Lehman's bankruptcy according to Table IX, whereas ownership by other hedge funds is not. Panel B reports the results of *F*-tests for comparisons between the effects of leveraged hedge funds and other types of institutional investors. As shown in columns (1) and (2) of Panel B, leveraged hedge funds have a greater effect on PEV during the Lehman crisis than unleveraged hedge funds, mutual funds, or other investor types. Thus, there is evidence that the mispricing following Lehman's failure was more severe for stocks held by hedge funds that use leverage. This finding is consistent with the view that the inability of leveraged hedge funds to roll over margin loans during the Lehman crisis resulted in fire sales. Taken together, the evidence from Lehman's bankruptcy provides additional support for the hypothesis that hedge fund deleveraging can adversely affect price efficiency in a crisis.

E. The quant meltdown in August 2007

During the week of August 6, 2007, a large number of equity-oriented quantitative hedge funds experienced unprecedented losses. Khandani and Lo (2011) argue that the rapid unwind of one or more sizable quantitative equity portfolios caused market dislocations, triggering stop-loss and deleveraging policies among leveraged equity-oriented hedge funds and resulting in fire sales. However, because these dislocations were short-lived and limited to quantitative equity-oriented strategies that use leverage, the tests reported in previous sections fail to find any adverse effect of hedge fund ownership on market efficiency during the third quarter of 2007. We therefore examine the period surrounding the quant meltdown using an event study methodology as in the analysis of Lehman Brothers' bankruptcy. In addition, we distinguish between different types of hedge funds according to their use of leverage.

Quantitative hedge funds typically employ substantial leverage to enhance returns on strategies that on an unleveraged basis would not yield attractive results. Khandani and Lo (2011) show that the decline in alphas on a number of statistical arbitrage strategies forced quantitative hedge funds to increase their leverage in the years leading to the August 2007 meltdown so as to maintain the level of

returns that investors have come to expect. Leverage has the effect of amplifying the profits and losses of the underling strategy, but it can also lead to sudden liquidations of large positions once credit is withdrawn or loss limits are reached. Such liquidations could decrease the price efficiency of the underlying securities.

Similar to the analysis of Lehman Brother's bankruptcy, we separate the stock holdings of leveraged hedge funds in the period prior to the quant meltdown to analyze whether the changes in price efficiency during the meltdown are related to ownership by leveraged hedge funds. The leveraged hedge fund companies hold 4.5% of the outstanding shares for the average sample stock in June 2007, whereas the unleveraged hedge fund companies hold about 2.9% of the outstanding shares. We combine the unleveraged holdings with those of unclassified hedge fund companies that account for 3.3% of outstanding shares.

Table X presents the estimates from cross-sectional regressions of changes in pricing error variance during the quant meltdown on stock holdings of leveraged hedge funds, holdings of unleveraged hedge funds and other types of institutional investors, and control variables. Changes in stock price efficiency are measured between the pre-crisis period from June 1–June 30, 2007, and the crisis period from July 15–August 15, 2007.

Panel A of Table X shows that stocks held by leveraged hedge funds experienced significantly greater increases in pricing error variance during the quant meltdown than other stocks. Holdings by other types institutional investors, including other hedge funds and mutual funds, are not significantly associated with changes in PEV during the quant meltdown. Panel B tests for differences between the effects of leveraged hedge funds and other institutional types on PEV, and it reveals that ownership by leveraged hedge funds had a significantly greater effect on PEV than ownership by other types of institutional investors. Considering that quant hedge funds are among those using leverage, the tests in Table X support the hypothesis that the quant meltdown of 2007 had an adverse effect on stock price efficiency.

F. Robustness analysis

In this section, we examine the sensitivity of the findings to alternative measures of price efficiency and analyze the significance of the effects of hedge fund ownership on price efficiency across different sub-samples. We also consider alternative regression specifications and an alternative alignment of the institutional ownership data with measures of informational efficiency. Finally, we examine whether our results could be due to reverse causality.

The multivariate results reported so far have used PEV to measure price efficiency. We now consider three alternative measures of price efficiency: (1) the ratio of pricing error variance to the total realized intraday variance (standardized PEV), (2) the ratio of 15- to 30-minute variance of stock returns, and (3) the autocorrelation of 30-minute stock returns. While the three measures are conceptually different, all of the measures should be larger for less efficiently priced stocks with a more gradual incorporation of new information into stock prices.

Table XI reports the baseline regression results for the three alternative efficiency measures. All of the alternative liquidity measures indicate that, on average, increased hedge fund ownership is significantly related to subsequent improvements in the informational efficiency of prices. For example, the results based on the standardized PEV measure show the marginal effect of a one standard deviation change in hedge fund ownership on the standardized PEV is negative 0.11 standard deviations (-2.07*0.04/0.73). Also, as Panel B of Table XI reports, changes in hedge fund holdings typically have a greater effect on these efficiency measures than changes in the holdings of mutual funds or other types of financial institutions.

Next, we examine whether the effects of hedge fund ownership on PEV differ for stocks traded on NYSE or NASDAQ, and estimate model (4) separately for stocks listed on NYSE (and AMEX) and stocks listed on NASDAQ. The results are generally quite similar for stocks listed on different exchanges. Hedge fund ownership has a significant negative effect on PEV in both sub-samples, and the effect is statistically greater in both sub-samples than the effect of ownership by banks, mutual

funds, or other types of financial institutions. We omit these results to conserve space, but they are available on request.

We also consider alternative specifications for the regression tests. Following Gompers and Metrick (2001), we decompose current institutional ownership (IO_t) into last period's institutional ownership (IO_{t-1}) and the change in institutional ownership (ΔIO_t), and examine the importance of both components for subsequent efficiency changes (ΔPEV_{t+1}). Specifically, we estimate the model in equation (3) with the lagged levels of institutional holdings among the control variables. As reported in Table XII, last periods' ownership is not significantly related to future efficiency changes after controlling for the changes in institutional ownership. This result indicates that the regression model based on the changes in institutional ownership that is used throughout the paper is well specified.

Another robustness test uses an alternative alignment of the institutional ownership data with measures of informational efficiency. The tests so far measure efficiency in quarter q over the first month following the report date for institutional holdings in quarter $q-1$. We also measure informational efficiency in quarter q as the average of informational efficiency measures in the first, second, and third month of quarter q. Short interest, standard deviation of intraday stock returns, share turnover, and the effective percentage bid-ask spread are also averaged over the entire quarter. The results (available on request) are not materially different from those obtained using efficiency measures from the first month in each quarter that are reported in Table VI.

Finally, we test whether the results could be driven by reverse causality. Specifically, we examine whether institutions tend to invest more in stocks that have recently improved in price efficiency. The results of the regressions of the changes in holdings of each investor type on last quarter's changes in efficiency measures are reported in Table XIII. There is no evidence that hedge funds buy stocks with increased efficiency as measured by PEV, although there is some evidence that banks and mutual funds buy such stocks. We find similar results when we repeat the test with the other efficiency

measures. Thus, the relation between hedge fund holdings and efficiency is unlikely to be driven by reverse causality.

V. Conclusion

Hedge funds have been portrayed both as rational arbitrageurs who improve market efficiency by exploiting securities' mispricing and as leveraged speculators whose active trading strategies can destabilize markets. To distinguish between these two hypotheses, we analyze the effects of hedge fund ownership on the informational efficiency of prices in a cross-section of stocks. Overall, the findings support the hypothesis that hedge fund trading improves the informational efficiency of stock prices. We find that, on average during the 2000–2012 sample period, stocks with increased hedge fund ownership experience significant decreases in PEV, return autocorrelations, and variance ratios compared to stocks with decreased hedge fund ownership. Furthermore, consistent with the hypothesis that hedge funds contribute more to informational efficiency than other types of institutional investors, we find that the effect of hedge fund ownership on stock price efficiency is greater than the effects of ownership by mutual funds, banks, or other financial institutions.

These findings support the hypothesis that hedge funds perform the role of rational arbitrageurs, conducting extensive research about the fundamental value of securities and taking advantage of any perceived mispricing. However, when we analyze the effects of hedge fund ownership on price efficiency during liquidity crises, we find that the results are consistent with the alternative hypothesis. Greater hedge fund ownership was associated with subsequent decreases in the informational efficiency of prices during liquidity crises, in particular if the hedge funds use leverage. Liquidity crises are characterized by large increases in the cost of funding for arbitrageurs as measured by the TED

spread. Thus, our findings suggest that the effect of hedge fund ownership on market efficiency depends on the availability of funding for arbitrage activities, and the necessity for unwinding positions rapidly in response to liquidity demands.

To understand the channels through which hedge funds can reduce price efficiency in a crisis, we further analyze the changes in stock price efficiency around the bankruptcy of Lehman Brothers and during the 2007 quant meltdown. Lehman's failure caused liquidity problems for hedge funds that used Lehman as a prime broker, forcing them to liquidate more liquid assets such as stocks. We find that the price efficiency of stocks held by Lehman-connected hedge funds was adversely affected by Lehman's demise, as was the price efficiency of stocks held by leveraged hedge funds. Similarly, we find evidence during the quant crisis of 2007 that stocks held by hedge funds that use leverage experienced greater declines in price efficiency during the crisis. This evidence supports the theory of Brunnermeier and Pedersen (2009) and Mitchell and Pulvino (2012) that a shock to arbitrageurs such as hedge funds can cause assets in which arbitrageurs invest to be inefficiently priced.

Our findings are not sensitive to alternative measures of price efficiency, and they hold even when we control for changes in volatility, liquidity, short interest, or other stock characteristics. Although higher institutional holdings typically also reduce stock price volatility and increase liquidity and short interest, these changes do not fully explain the improvements in price efficiency associated with greater hedge fund ownership. When we control for contemporaneous changes in stock volatility and liquidity, we find that hedge fund ownership has an orthogonal effect on stock price efficiency. In contrast, mutual fund and bank ownership has no effect on stock price efficiency after accounting for volatility and liquidity changes, lending support to the hypothesis that hedge fund trading improves market efficiency by incorporating information into stock prices, whereas non-hedge fund trading affects efficiency mostly by increasing liquidity.

We conclude that hedge fund ownership positively contributes to the informational efficiency of stock prices but its effect can become negative during liquidity crises. These findings provide new insights into the effects of hedge funds on the quality and functioning of financial markets.

References

Agarwal, Vikas, Wei Jiang, Yuehua Tang, and Baozhong Yang, 2013, Uncovering hedge fund skills from the portfolio holdings they hide, *Journal of Finance 68*, 739–783.

Agarwal, Vikas, Naveen D. Daniel, and Narayan Y. Naik, 2009, Role of Managerial Incentives and Discretion in Hedge Fund Performance, *Journal of Finance 64*, 2221–2256.

Ang, Andrew, Sergiy Gorovyy, and Gregory B. Inwegen, 2011, Hedge fund leverage, *Journal of Financial Economics 102*, 102–126.

Aragon, George O., and Philip E. Strahan, 2012, Hedge funds as liquidity providers: Evidence from the Lehman bankruptcy, *Journal of Financial Economics 103,* 570–587.

Bessembinder, Hendrik, 2003, Issues in assessing trade execution costs, *Journal of Financial Markets 102*, 233–257.

Beveridge, Stephen, and Charles R. Nelson, 1981, A new approach to decomposition of economic time series into permanent and transitory components with particular attention to measurement of the business cycle, *Journal of Monetary Economics 102*, 151–174.

Billo, Monica, Mila Getmansky, Andrew W. Lo, and Loriana Pelizzon, 2012, Econometric measures of connectedness and systemic risk in the finance and insurance sectors, *Journal of Financial Economics 104*, 535–559.

Boehmer, Ekkehart, and Eric K. Kelly, 2009, Institutional investors and the informational efficiency of prices, *Review of Financial Studies 22*, 3563–3594.

Boehmer, Ekkehart, and Juan Wu, 2013, Short selling and the price discovery process, *Review of Financial Studies 26*, 287–322.

Boyson, Nicole M., Christof W. Stahel, and Rene M. Stulz, 2010, Hedge fund contagion and liquidity shocks, *Journal of Finance 65*, 1789–1816.

Brav, Alon, Wei Jiang, Frank Partnoy, and Randall Thomas, 2008, Hedge fund activism, corporate governance, and firm performance, *Journal of Finance 63*, 1729–1775.

Brown, Stephen, William Goetzmann, Bing Liang, and Christopher Schwarz, 2012, Trust and delegation, *Journal of Financial Economics 103*, 221–234.

Brunnermeier, Markus K., and Lasse H. Pedersen, 2009, Market liquidity and funding liquidity, *Review of Financial Studies 22*, 2201–2238.

Brunnermeier, Markus K., and Stefan Nagel, 2004, Hedge funds and the technology bubble, *Journal of Finance 59*, 2013–2040.

Cao, Charles, Yong Chen, Bing Liang, and Andrew W. Lo, 2013, Can hedge funds time market liquidity?, *Journal of Financial Economics 109*, 493–516.

Chen, Hsiu-Lang, Narasimhan Jegadeesh, and Russ Wermers, 2000, The value of active mutual fund management: An examination of the stockholdings and trades of fund managers, *Journal of Financial and Quantitative Analysis 35*, 343–368.

Chordia, Tarun, Richard Roll, and Avanidhar Subrahmanyam, 2005, Evidence on the speed of convergence to market efficiency, *Journal of Financial Economics 76*, 271–292.

Dasgupta, Amil, Andrea Prat, and Michela Verardo, 2011, Institutional trade persistence and long-term equity returns, *Journal of Finance 66*, 635–652.

Cohen, Lauren, and Breno Schmidt, 2009, Attracting flows by attracting big clients, *Journal of Finance 64*, 2125–2151.

Dow, James, and Gary Gorton, 1997, Stock market efficiency and economic efficiency: Is there a connection? *Journal of Finance 52*, 1087–1129.

Dow, James, and Rohit Rahi, 2003, Informed trading, investment, and welfare, *Journal of Business 76*, 439–454.

Fama, Eugene F., and James D. MacBeth, 1973, Risk, returns, and equilibrium: Empirical tests, *Journal of Political Economy 81*, 307–636.

Fung, William, and David A. Hsieh, 2000, Measuring the market impact of hedge funds, *Journal of Empirical Finance 7*, 1–36.

Gompers, Paul A, and Andrew Metrick, 2001, Institutional investors and equity prices, *Quarterly Journal of Economics 116*, 229–259.

Griffin, John M., Jeffrey H. Harris, Tao Shu, and Selim Topaloglu, 2011, Who drove and bust the tech bubble?, *Journal of Finance 66*, 1251–1290.

Grossman, Sanford J., and Joseph E. Stiglitz, 1980, On the impossibility of informationally efficient markets, *American Economic Review 70*, 393–408.

Hasbrouck, Joel, 1993, Assessing the quality of a security market: A new approach to transaction cost measurement, *Review of Financial Studies 6*, 192–212.

Khandani, Amir E., and Andrew W. Lo, 2011, What happened to the quants in August 2007?: Evidence from factors and transactions data, *Journal of Financial Markets 14*, 1–46.

Lee, Charles M., and Mark J. Ready, 1991, Inferring trade direction from intraday data, *Journal of Finance 46*, 733–746.

Lewellen, Jonathan, 2011, Institutional investors and the limits of arbitrage, *Journal of Financial Economics 102*, 62–80.

Lo, Andrew W., 2008, Hedge funds, systemic risk, and the financial crisis of 2007–2008. Written testimony for the U.S. House of Representatives Committee on Oversight and Government Reform." Working paper, MIT and NBER.

Lo, Andrew W., and Craig MacKinlay, 1988, Stock market prices do not follow random walks: Evidence from a simple specification test, *Review of Financial Studies 1*, 41–66.

Manconi, Alberto, Massimo Massa, and Ayako Yasuda, 2012, The role of institutional investors in propagating the crisis of 2007–2008, *Journal of Financial Economics 104*, 491–518.

Mitchell, Mark, and Todd Pulvino, 2012, Arbitrage crashes and the speed of capital, *Journal of Financial Economics 104*, 469–490.

Pagano, Marco, 1989, Endogenous market thinness and stock price volatility, *Review of Economic Studies 56*, 269–287.

Petersen, Mitchell A., 2009, Estimating standard errors in finance panel data sets: Comparing approaches, *Review of Financial Studies 22*, 438–480.

Ronen, Tavy, 1997, Tests and properties of variance ratios in microstructure studies, *Journal of Financial and Quantitative Analysis 32*, 183–204.

Saffi, Pedro A., and Kari Sigurdsson, 2010, Price efficiency and short selling, *Review of Financial Studies 24*, 822–851.

Stein, Jeremy C., 2009, Presidential address: Sophisticated investors and market efficiency, *Journal of Finance 54*, 1517–1548.

Teo, Melvyn, 2011, The liquidity risk of liquid hedge funds, *Journal of Financial Economics 100*, 24–44.

Tobin, James, 1969, A general equilibrium approach to monetary theory, *Journal of Money, Credit and Banking 1*, 15–29.

Yan, Xuemin, and Zhe Zhang, 2009, Institutional investors and equity returns: Are short-term institutions better informed? *Review of Financial Studies 22*, 893–924.

Figure 1: Percentage of shares held by hedge funds

This figure plots the average percentage of shares held by hedge funds for the sample stocks over the 2000:Q1–2012:Q4 period. Sample stocks are listed on NYSE, AMEX, or NASDAQ. Institutional ownership data come from 13F reports. We classify 1,594 filers of 13F reports as hedge management firms based on information from hedge fund databases and SEC Form ADV.

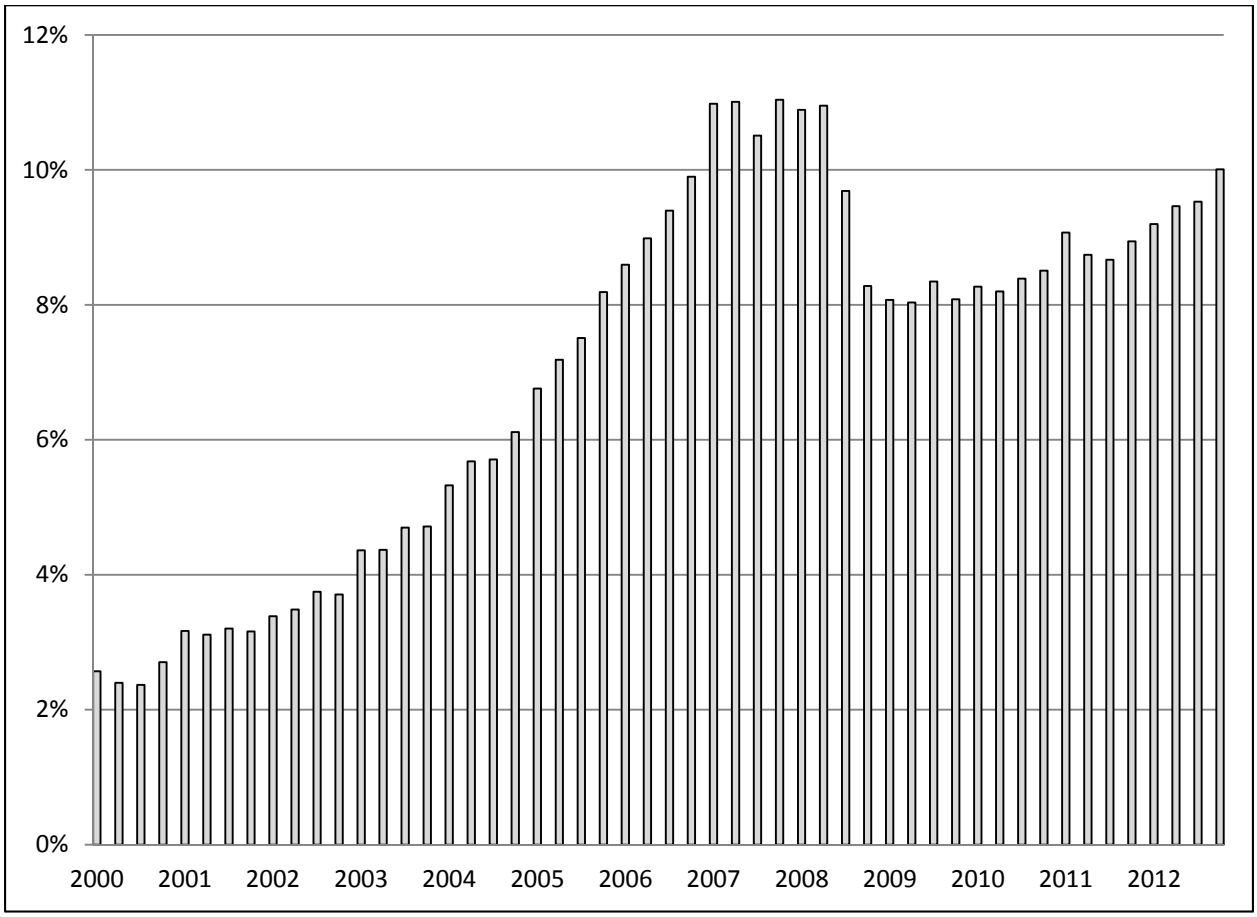

Figure 2: Number of stocks bought and sold by hedge funds

This figure depicts the number of stocks in portfolios sorted according to quarterly changes in hedge fund ownership from 2000 to 2012. Portfolio "Buy" includes stocks for which hedge funds increase their holdings by more than 1% of shares outstanding in a given quarter, and portfolio "Sell" includes stocks for which hedge funds decrease their holdings by more than 1% of shares outstanding in a given quarter. The figure also plots the difference between the number of stocks in the "Buy" and "Sell" portfolio.

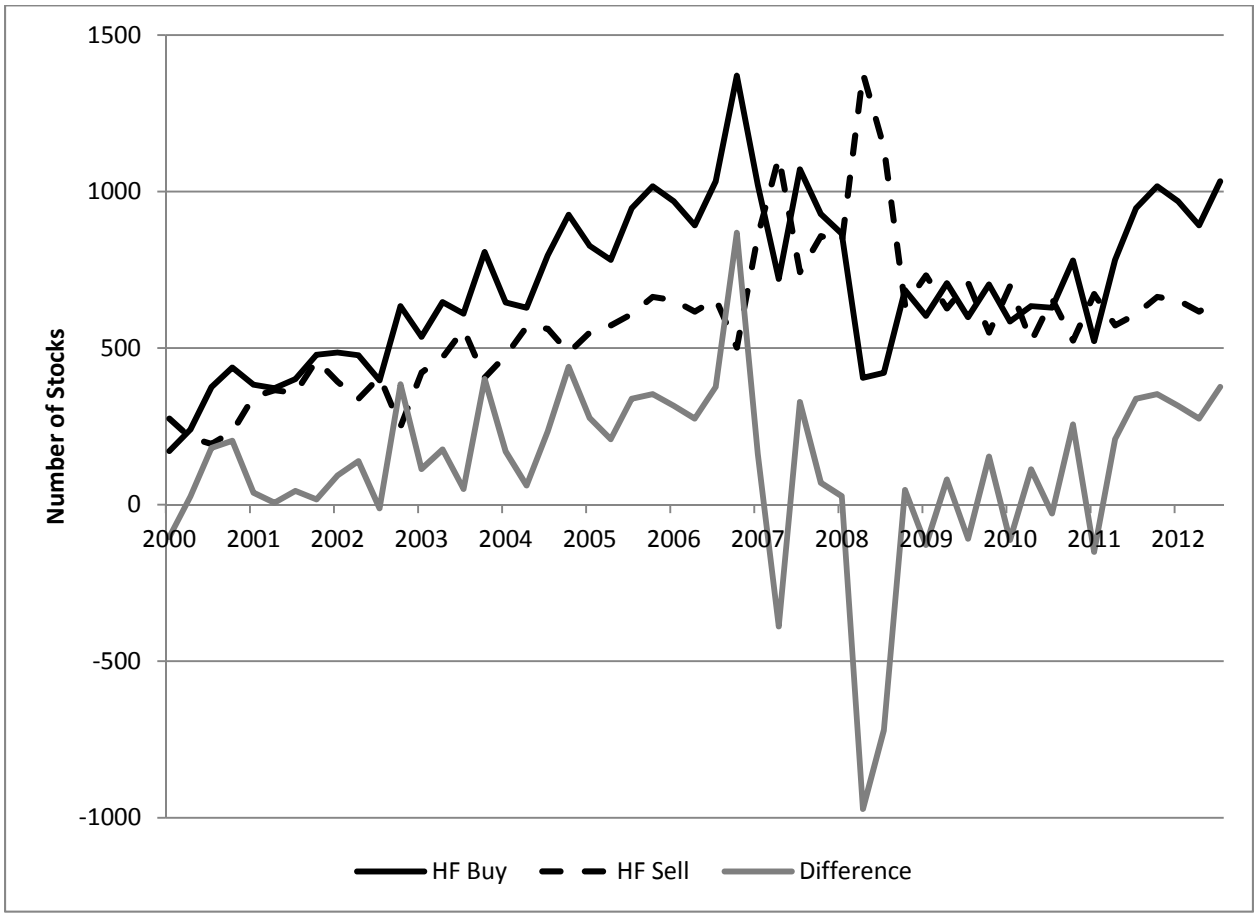

Figure 3: Time series of the effect hedge fund holdings on price efficiency

The solid line shows the time series of the estimated effect of hedge fund ownership on price efficiency from the regressions of quarterly changes in PEV on lagged changes in institutional holdings in column (1) of Table VI. The dashed line plots the spread between the 3-month U.S. dollar LIBOR rate and the 3-month T-bill rate (TED spread).

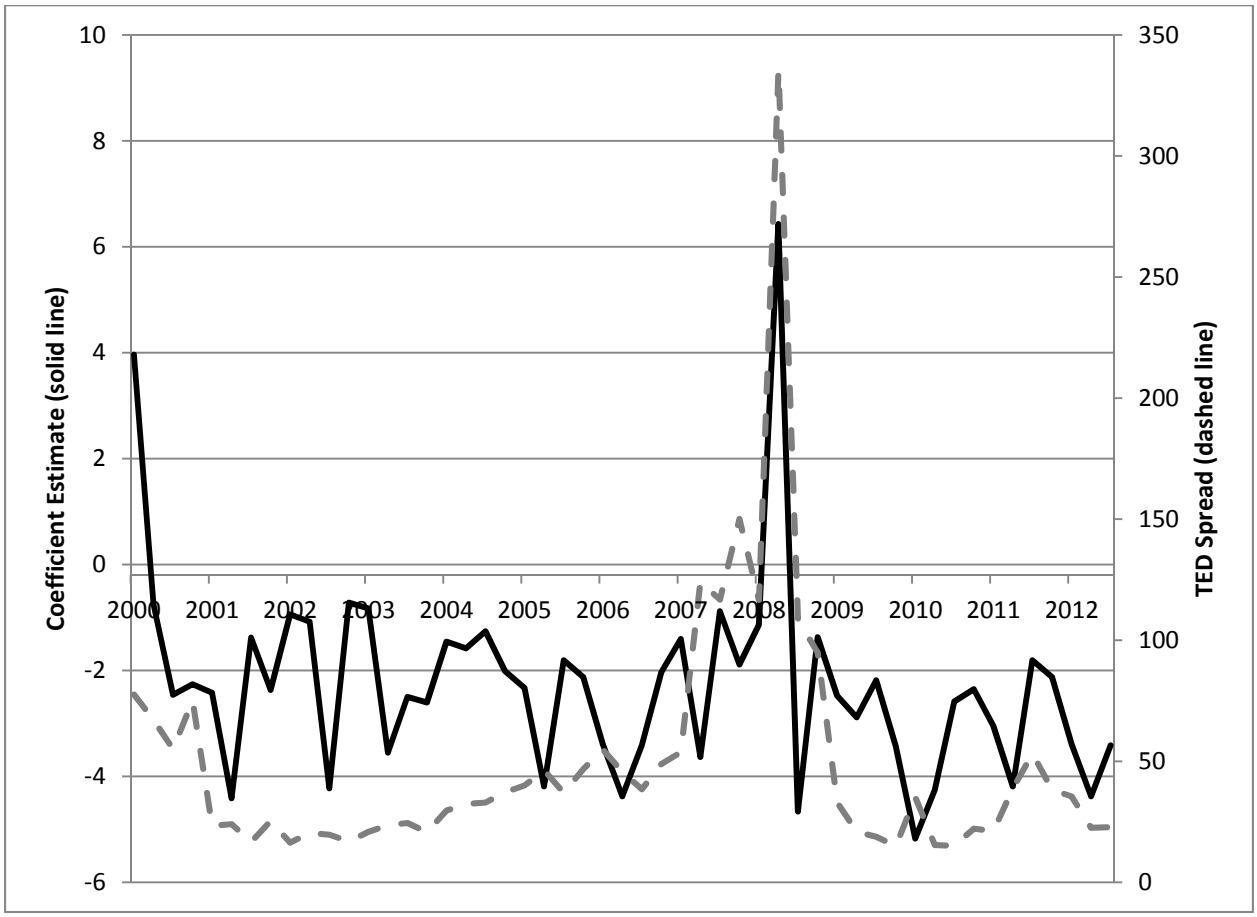

Figure 4: Percentage of shares held by leveraged and un-leveraged hedge fund managers

This figure plots the average percentage of outstanding shares held by leveraged and un-leveraged hedge fund management firms. A hedge fund firm is classified as leveraged in a given quarter if the AUM of its equity-oriented funds that use leverage is greater than the AUM of its equity-oriented funds that do not use leverage. Data on hedge fund leverage are from TASS, HFR, CISDM, Barclay Hedge, and Morningstar. Sample stocks are listed on NYSE, AMEX, or NASDAQ.

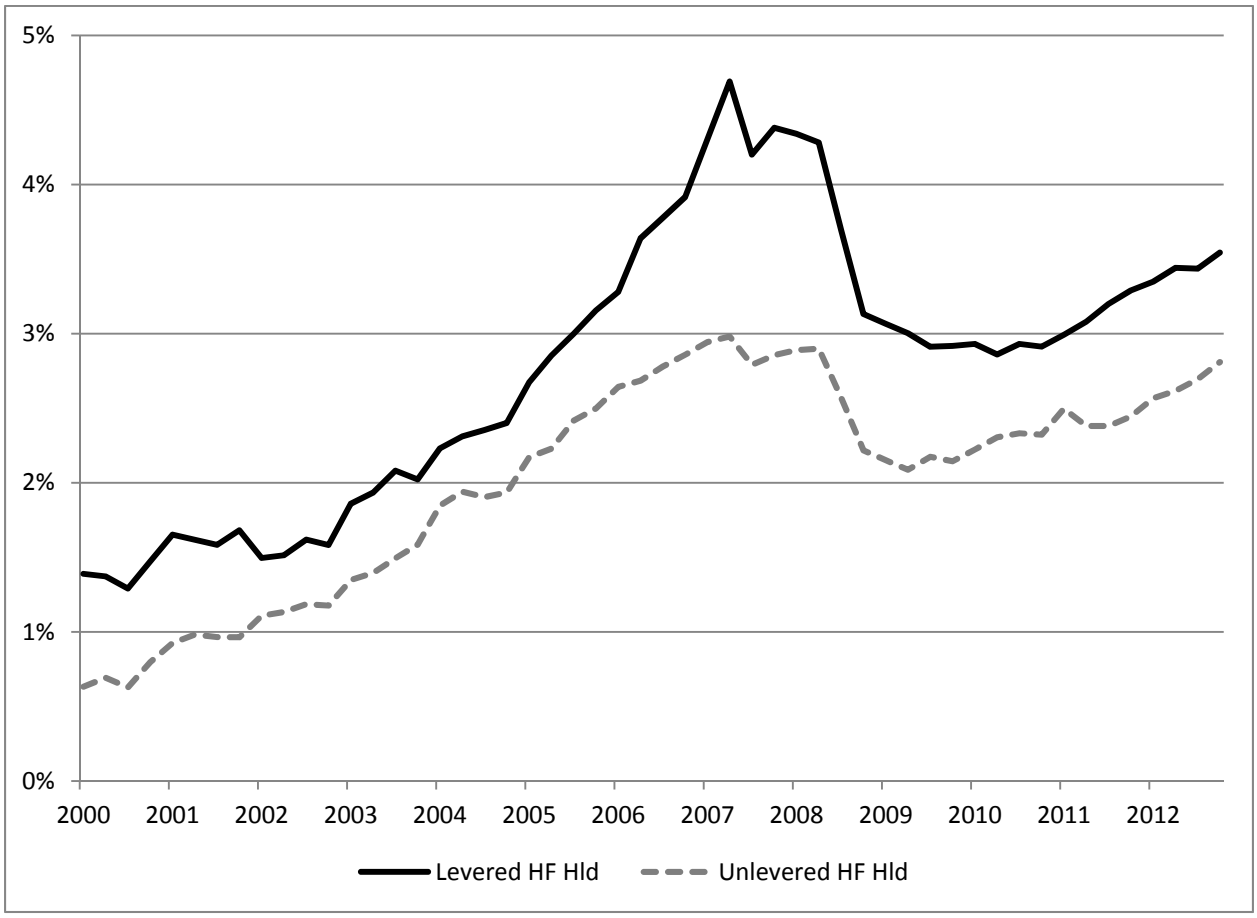

Figure 5: Changes in price efficiency and holdings of Lehman-connected hedge funds

This figure plots the percentage change in PEV between the period preceding (August 1–August 31, 2008) and following (September 15–October 15, 2008) the bankruptcy of Lehman Brothers. Stocks are grouped based on the fraction of shares held by Lehman-connected hedge funds as of June 30, 2008.

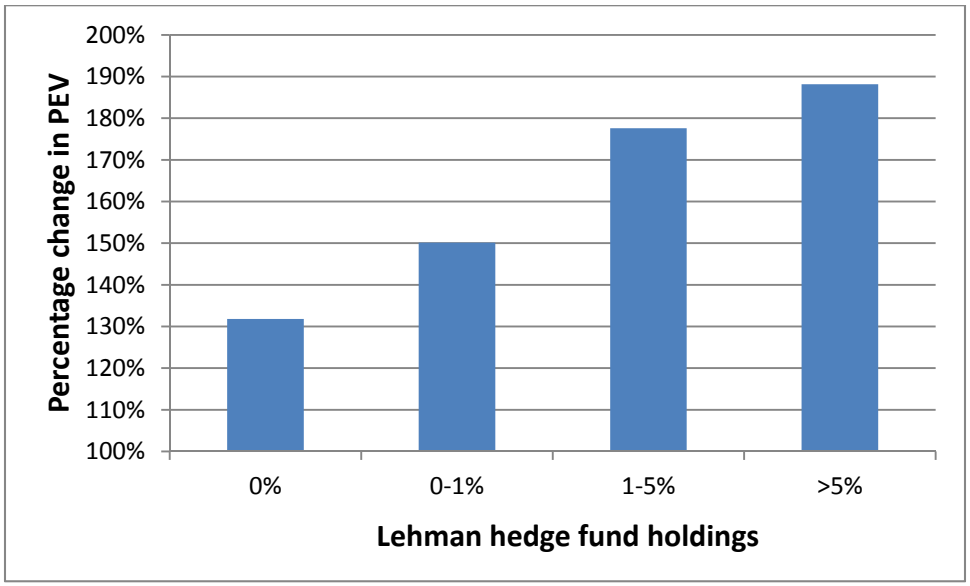

Table I: Summary statistics

This table reports summary statistics for measures of price efficiency (Panel A), institutional ownership (Panel B), and other control variables (Panel C) from 2000 to 2012. The columns show time series averages of the cross-sectional means, medians, and standard deviations. PEV is the pricing error standard deviation. Standardized PEV is the ratio of pricing error standard deviation to the standard deviation of log transaction prices, expressed in percent. Variance ratio is the absolute value of the difference between the ratio of 15-to-30 minute stock return variance and one. Autocorrelation is the absolute value of 30-minute midpoint return autocorrelation. Institutional ownership is measured by the fraction of outstanding shares held by different categories of institutional investors at the end of quarter *q–1*. The category "others" includes non-hedge fund investment advisers, foundations, endowments, and private pension funds. Short interest ratio is the number of shares held short divided by the number of shares outstanding. Total assets are measured in billions of dollars at the end of quarter *q–1*. Book-to-market ratio is the book value of total shareholders' equity divided by the market value of equity. Leverage is the sum of current liabilities and long-term debt over total book assets measured at the end of *q–1*. Standard deviation is computed from the log of intraday transactions prices. Turnover is the ratio of the annualized trading volume and the number of outstanding shares. Bid-ask spread is the volume-weighted effective percentage bid-ask spread. NASDAQ dummy equals one for stocks listed on NASDAQ and zero otherwise.

Variable	Mean	Median	Standard deviation	2000–2003 Mean	2004–2007 Mean	2008–2012 Mean
Panel A: Measures of price efficiency						
Pricing error variance (PEV)	4.81	4.77	0.52	5.54	4.32	4.60
Standardized PEV	3.32	3.30	0.73	3.80	3.04	3.17
Variance ratio (15/30 min)	0.38	0.19	0.84	0.48	0.35	0.33
Autocorrelation (30 min)	0.16	0.11	0.17	0.19	0.15	0.15
Panel B: Institutional holdings						
Banks and insurance	0.14	0.14	0.04	0.13	0.15	0.13
Mutual funds	0.32	0.32	0.06	0.31	0.32	0.34
Hedge funds	0.07	0.05	0.04	0.03	0.08	0.09
Others	0.12	0.11	0.04	0.09	0.12	0.14
No. of institutional investors	175	120	19.91	163	170	190
Panel B: Control variables						
Short interest ratio	0.05	0.03	0.03	0.03	0.05	0.06
Total assets ($ billions)	11.73	0.98	0.14	9.49	11.59	13.62
Book-to-market	0.57	0.45	0.41	0.56	0.47	0.65
Leverage	0.21	0.17	0.06	0.21	0.21	0.22
Standard deviation	1.42	1.12	0.56	1.84	1.12	1.33
Turnover	2.74	1.79	3.84	2.60	2.66	2.91
Bid-ask spread (%)	0.31	0.19	0.20	0.50	0.21	0.24
NASDAQ dummy	0.51	0.71	0.02	0.52	0.52	0.50
Stocks per quarter	2915	–	–	2460	3189	3060

Table II: Summary statistics by hedge fund holdings

This table reports summary statistics for portfolios of stocks sorted quarterly into terciles by hedge fund holdings. The columns show time series averages of the cross-sectional means for each of the three portfolios from 2000 to 2012, and the difference between the high hedge fund ownership portfolio and the low hedge fund ownership portfolio. Standard errors are computed using the Newey-West procedure with four lags. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Hedge fund ownership tercile			
Variable	Low	Medium	High	High–Low
	Panel A: Measures of price efficiency			
PEV	4.72	4.66	5.04	0.32***
Standardized PEV	3.34	3.17	3.46	0.12*
Variance ratio (15/30 min)	0.37	0.34	0.44	0.06***
Autocorrelation (30 min)	0.16	0.15	0.18	0.02**
	Panel B: Other variables			
Short interest ratio	0.03	0.05	0.06	0.03***
Total assets ($ billions)	24.53	7.91	2.44	-21.79***
Book-to-market	0.56	0.56	0.58	0.02
Leverage	0.21	0.20	0.23	0.02***
Standard deviation	1.31	1.39	1.57	0.25***
Turnover	2.08	2.83	3.30	1.22***
Bid-ask spread (%)	0.35	0.27	0.32	-0.03*
NASDAQ dummy	0.45	0.50	0.59	0.14***
Non-hedge fund ownership	0.51	0.62	0.57	0.06**
Hedge fund ownership	0.01	0.05	0.14	0.13***
Avg. no of stocks per quarter	972	972	972	972

Table III: Changes in informational efficiency following changes in hedge fund holdings

This table reports quarterly changes in the informational efficiency of prices for stock portfolios sorted according to lagged changes in hedge fund holdings. The sample period is from 2000 to 2012. Portfolio "Sell" includes stocks for which hedge funds decrease their holdings by more than 1% of shares outstanding from quarter to quarter. Portfolio "Buy" includes stocks for which hedge funds increase their holdings by more than 1% of shares outstanding. Portfolio "No Change" includes all other stocks. All changes are measured as deviations from cross-sectional means in each quarter. The last column shows the difference between the portfolios bought and sold by hedge funds. The second part of the table shows the changes in hedge fund holdings in the subsequent quarter, and the number of stocks in each portfolio. Standard errors are computed using the Newey-West procedure with four lags. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Change in hedge fund holdings (q)			
Δ Efficiency measure (q+1)	Sell	No change	Buy	Buy–Sell
Pricing error variance (PEV)	0.026	0.031	-0.082***	-0.109***
Standardized PEV	0.036	0.016	-0.061***	-0.097***
Variance ratio (15/30 min)	0.010	0.017	-0.040***	-0.050***
Autocorrelation (30 min)	0.004	0.003	-0.008***	-0.012***
% of stocks HF buy (q+1)	15%	19%	36%	21%***
% of stocks HF sell (q+1)	13%	13%	33%	20%***
Avg. no. of stocks per quarter	586	1378	707	

Table IV: Changes in informational efficiency by firm size

This table reports quarterly changes in the informational efficiency of prices for stock portfolios sorted according to lagged changes in hedge fund holdings and size. The sample period is from 2000 to 2012. Portfolio "Sell" includes stocks for which hedge funds decrease their holdings by more than 1% of shares outstanding from quarter to quarter. Portfolio "Buy" includes stocks for which hedge funds increase their holdings by more than 1% of shares outstanding. Portfolio "No Change" includes all other stocks. All changes are measured as deviations from cross-sectional means in each quarter. The last column shows the difference between the portfolios bought and sold by hedge funds. Standard errors are computed using the Newey-West procedure with four lags. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Change in hedge fund holdings (q)			
Δ Efficiency measure (q+1)	Sell	No change	Buy	Buy–Sell
		Size quartile 1 (small)		
Pricing error variance (PEV)	0.043	0.053	-0.114***	-0.157***
Standardized PEV	0.079	0.049	-0.139***	-0.218***
Variance ratio (15/30 min)	0.015	0.047	-0.081***	-0.096***
Autocorrelation (30 min)	0.008	0.008	-0.019***	-0.027***
Avg. no. of stocks per quarter	170	297	201	
		Size quartile 2		
Pricing error variance (PEV)	0.032	0.038	-0.087***	-0.118***
Standardized PEV	0.032	0.014	-0.050*	-0.082**
Variance ratio (15/30 min)	0.014	0.022	-0.046***	-0.061***
Autocorrelation (30 min)	0.002	0.004	-0.008*	-0.009*
Avg. no. of stocks per quarter	163	308	196	
		Size quartile 3		
Pricing error variance (PEV)	0.020	0.024	-0.059*	-0.078**
Standardized PEV	0.018	0.007	-0.027	-0.045*
Variance ratio (15/30 min)	0.006	0.006	-0.015	-0.021
Autocorrelation (30 min)	0.002	0.000	-0.002	-0.003
Avg. no. of stocks per quarter	152	328	187	
		Size quartile 4 (large)		
Pricing error variance (PEV)	-0.001	0.016	-0.059*	-0.059*
Standardized PEV	-0.003	0.002	-0.005	-0.002
Variance ratio (15/30 min)	0.001	0.001	-0.002	-0.003
Autocorrelation (30 min)	0.002	0.000	0.000	-0.002
Avg. no. of stocks per quarter	101	445	123	

Table V: Changes in informational efficiency following changes in mutual fund holdings

This table reports quarterly changes in the informational efficiency of prices for stock portfolios sorted according to lagged changes in mutual fund holdings. The sample period is from 2000 to 2012. Portfolio "Sell" includes stocks for which mutual funds decrease their holdings by more than 1% of shares outstanding from quarter to quarter. Portfolio "Buy" includes stocks for which mutual funds increase their holdings by more than 1% of shares outstanding. Portfolio "No Change" includes all other stocks. All changes are measured as deviations from cross-sectional means in each quarter. The last column shows the difference between the portfolios bought and sold by mutual funds. The second part of the table shows the changes in mutual fund holdings in the subsequent quarter, and the number of stocks in each portfolio. Standard errors are computed using the Newey-West procedure with four lags. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Change in mutual fund holdings (q)			
Δ Efficiency measure (q+1)	Sell	No Change	Buy	Buy–Sell
Pricing error variance (PEV)	0.014	0.006	-0.016**	-0.030**
Standardized PEV	0.024	-0.012	-0.013*	-0.037*
Variance ratio (15/30 min)	0.010	0.001	-0.009	-0.020*
Autocorrelation (30 min)	0.002	0.000	-0.002	-0.004*
% of stocks MF buy (q+1)	24%	39%	43%	19%***
% of stocks MF sell (q+1)	32%	25%	38%	6%
Avg. no. of stocks per quarter	923	706	1043	

Table VI: Cross-sectional regressions of changes in PEV on changes in institutional holdings

This table shows estimates from cross-sectional regressions of quarterly changes in pricing error variance (PEV) on lagged changes in institutional holdings and several control variables. The estimates reported are time series means of quarterly regression slopes from 2000 to 2012. The average number of firms per quarter is 2,671. Standard errors (in parentheses) are computed from the time series of coefficient estimates using the Newey-West procedure with four lags. Panel B shows tests of the hypothesis that hedge funds have the same marginal effect on PEV as other types of financial institutions. The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	(1)	(2)	(3)
Intercept	0.11	0.13	0.05
	(0.07)	(0.08)	(0.07)
Δ Hedge fund hldg.	-2.25***	-2.01***	-1.69***
	(0.29)	(0.33)	(0.30)
Δ Mutual fund hldg.	-0.46***	-0.25*	-0.07
	(0.18)	(0.14)	(0.13)
Δ Bank and insurance hldg.	-0.28**	-0.10	-0.03
	(0.13)	(0.11)	(0.07)
Δ Others hldg.	-0.19	-0.08	0.09
	(0.16)	(0.15)	(0.13)
Δ Log of no. of owners	-0.58***	-0.48***	-0.28***
	(0.06)	(0.05)	(0.04)
Lagged PEV	-0.04***	-0.04***	-0.03***
	(0.01)	(0.01)	(0.01)
Δ Short interest ratio	-	-0.32***	-0.09
	-	(0.10)	(0.11)
Δ Log of total assets	-	-0.27***	-0.13***
	-	(0.03)	(0.02)
Δ Book-to-market	-	0.37***	0.15***
	-	(0.05)	(0.03)
Δ Leverage	-	0.34***	0.17***
	-	(0.05)	(0.03)
Δ Log of standard deviation	-	-	0.14***
	-	-	(0.01)
Δ Turnover	-	-	-0.05***
	-	-	(0.01)
Δ Effective spread	-	-	1.74***
	-	-	(0.20)
R^2	0.09	0.11	0.32

Panel B: Tests for differences between the effects of hedge funds and other types of financial institutions on PEV

	(1)	(2)	(3)
HF – Mutual funds	-1.79***	-1.76***	-1.62***
	[28.27]	[24.37]	[25.13]
HF – Banks and insurance	-1.97***	-1.91***	-1.66***
	[37.07]	[30.86]	[29.83]
HF – Others	-2.06***	-1.93***	-1.78***
	[37.45]	[28.73]	[30.34]

Table VII: Panel regressions of changes in PEV on changes in leveraged hedge fund holdings in normal times and during liquidity crises

This table reports estimates from panel regressions of quarterly changes in pricing error variance (PEV) on lagged changes in institutional holdings and control variables. Hedge fund holdings are divided according to use of leverage. Ownership variables are interacted with a dummy variable that is set to one if the TED spread exceeds 1.5% (*Crisis Dummy*). There are two liquidity crises during the 2000–2012 sample period—2008:Q2 and 2008:Q4. The total number of stock/quarter observations is 136,259. The regressions are estimated with time fixed effects, and standard errors (in parentheses) are adjusted for clustering by quarter and by firm. Panel B shows tests of the hypothesis that leveraged hedge funds have the same marginal effect on PEV as other types of financial institutions during the entire sample period (based on column (1) in Panel A), if there is no liquidity crisis (based on column (2) in Panel A), and during liquidity crises (based on column (2) in Panel A). The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	(1)	(2)	(3)	(4)
Δ Leveraged HF hldg.	-1.29***	-1.60***	-1.50***	-1.35***
	(0.30)	(0.18)	(0.17)	(0.15)
Δ Other HF hldg.	-1.18***	-1.28***	-1.17***	-1.11***
	(0.17)	(0.15)	(0.14)	(0.13)
Δ Mutual fund hldg.	-0.32***	-0.28***	-0.14	-0.05
	(0.12)	(0.11)	(0.10)	(0.08)
Δ Bank and insurance hldg.	-0.23*	-0.17**	-0.07	-0.01
	(0.13)	(0.12)	(0.12)	(0.09)
Δ Others hldg.	-0.10	-0.08	-0.02	0.09
	(0.13)	(0.13)	(0.12)	(0.09)
Δ Log of no. of owners	-0.37***	-0.37***	-0.32***	-0.22***
	(0.13)	(0.07)	(0.06)	(0.02)
Lagged PEV	-0.04***	-0.04***	-0.05***	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)
Δ Leveraged HF hldg. x Crisis Dummy	-	4.57**	4.37**	4.57**
	-	(1.93)	(1.81)	(2.41)
Δ Other HF hldg. x Crisis Dummy	-	1.32	1.34	1.10
	-	(1.06)	(1.04)	(0.88)
Δ Mutual fund hldg. x Crisis Dummy	-	-0.96***	-0.98***	-0.83***
	-	(0.11)	(0.13)	(0.07)
Δ Bank and insurance hldg. x Crisis Dummy	-	-1.77***	-1.66***	-0.56***
	-	(0.31)	(0.30)	(0.19)
Δ Others hldg. x Crisis	-	-0.15	-0.17	-0.34***
	-	(0.28)	(0.28)	(0.12)
Δ Firm characteristics	No	No	Yes	Yes
Δ Liquidity	No	No	No	Yes
R^2	0.05	0.07	0.10	0.34

Panel B: Tests for differences between the effects of leveraged hedge funds and other types of financial institutions on PEV

	Entire time period from col. (1)	No liquidity crises from col. (2)	Liquidity crises from col. (2)
Leveraged HF – Other HF	-0.11	-0.32	2.93***
	[0.27]	[2.56]	[10.37]
Leveraged HF – Mutual funds	-0.97***	-1.32***	4.21**
	[8.85]	[47.61]	[4.57]
Leveraged HF – Banks and insurance	-1.06***	-1.43***	4.91**
	[8.98]	[43.69]	[4.93]
Leveraged HF – Others	-1.19***	-1.52***	3.20*
	[14.41]	[56.56]	[3.62]

Table VIII: Cross-sectional regressions of changes in PEV on ownership by Lehman-connected hedge funds during Lehman's bankruptcy

This table reports estimates from cross-sectional regressions of changes in pricing error variance following the bankruptcy of Lehman Brothers on the stock holdings of Lehman-connected hedge funds, holdings of non-Lehman hedge funds, holdings of other types of institutional investors, and control variables. The changes in stock price efficiency are computed between the pre-crisis period August 1–August 31 and the crisis period September 15–October 15. The number of observations (stocks) is 3,071. Standard errors are in parentheses below the estimates. Panel B shows tests of the hypothesis that Lehman-connected hedge funds have the same marginal effect on PEV as other types of financial institutions. The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	(1)	(2)	(3)
Intercept	4.54***	4.42***	3.53***
	(0.38)	(0.37)	(0.33)
Lehman HF hldg.	2.26***	2.19***	1.01***
	(0.75)	(0.72)	(0.33)
Non-Lehman HF hldg.	0.88***	0.75***	0.48***
	(0.21)	(0.19)	(0.13)
Mutual fund hldg.	-0.46***	-0.51***	-0.18*
	(0.12)	(0.13)	(0.10)
Bank and insurance hldg.	-0.53*	-0.52*	-0.18
	(0.29)	(0.29)	(0.29)
Others hldg.	-0.12	-0.12	-0.07
	(0.22)	(0.22)	(0.16)
Log of no. of owners	-0.25***	-0.19***	-0.16***
	(0.05)	(0.06)	(0.05)
Lagged PEV	-0.34***	-0.35***	-0.30***
	(0.03)	(0.03)	(0.03)
Short interest ratio	-	-0.35	-0.13
	-	(0.24)	(0.18)
Log of total assets	-	-0.03	0.02
	-	(0.02)	(0.02)
Book-to-market	-	0.14***	0.05*
	-	(0.05)	(0.02)
Leverage	-	0.28**	0.21**
	-	(0.11)	(0.08)
Δ Log of standard deviation	-	-	-0.35
	-	-	(0.55)
Δ Turnover	-	-	-0.06***
	-	-	(0.02)
Δ Effective spread	-	-	0.62***
	-	-	(0.10)
R^2	0.21	0.23	0.24

Panel B: Tests for differences between the effects of Lehman-connected hedge funds and other types of financial institutions on PEV

	(1)	(2)	(3)
Lehman HF – Non-Lehman HF	1.38**	1.44**	0.53
	[4.00]	[4.68]	[2.45]
Lehman HF – Mutual funds	2.72***	2.70***	1.20***
	[12.24]	[12.52]	[11.72]
Lehman HF – Banks and insurance	2.79***	2.71***	1.20***
	[12.95]	[13.28]	[9.04]
Lehman HF – Others	2.38***	2.32***	1.09***
	[8.55]	[8.71]	[8.79]

Table IX: Cross-sectional regressions of changes in PEV on leveraged hedge fund holdings during Lehman's bankruptcy

This table reports estimates from cross-sectional regressions of changes in pricing error variance following the bankruptcy of Lehman Brothers on the stock holdings in June 2008 of hedge funds using leverage, holdings of other hedge funds, and holdings of other types of institutional investors. The changes in stock price efficiency are computed between the pre-crisis period August 1–August 31 and the crisis period September 15–October 15. The number of observations (stocks) is 3,071. Standard errors are in parentheses below the estimates. Panel B shows tests of the hypothesis that leveraged hedge funds have the same marginal effect on PEV as other types of financial institutions. The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	(1)	(2)	(3)
Intercept	4.48***	4.37***	3.57***
	(0.38)	(0.37)	(0.33)
Leveraged HF hldg.	1.68***	1.50***	0.73***
	(0.44)	(0.40)	(0.23)
Other HF hldg.	0.39	0.41	0.24
	(0.45)	(0.45)	(0.32)
Mutual fund hldg.	-0.41***	-0.40***	-0.20**
	(0.11)	(0.13)	(0.09)
Bank and insurance hldg.	-0.54*	-0.56*	-0.19
	(0.29)	(0.30)	(0.28)
Others hldg.	-0.08	-0.04	-0.10
	(0.22)	(0.22)	(0.16)
Log of no. of owners	-0.24***	-0.24***	-0.14***
	(0.05)	(0.05)	(0.04)
Lagged PEV	-0.34***	-0.34***	-0.31***
	(0.03)	(0.03)	(0.03)
Short interest ratio	-	-0.18	-0.10
	-	(0.26)	(0.19)
Log of total assets	-	0.01	0.02
	-	(0.02)	(0.02)
Book-to-market	-	0.12***	0.06***
	-	(0.04)	(0.02)
Leverage	-	0.26***	0.24***
	-	(0.10)	(0.07)
Δ Log of standard deviation	-	-	-0.33
	-	-	(0.56)
Δ Turnover	-	-	-0.06**
	-	-	(0.02)
Δ Effective spread	-	-	0.60***
	-	-	(0.09)
R^2	0.21	0.22	0.24

Panel B: Tests for differences between the effects of leveraged hedge funds and other types of financial institutions on PEV

	(1)	(2)	(3)
Leveraged HF – Other HF	1.29**	1.09*	0.49
	[4.51]	[3.23]	[1.31]
Leveraged HF – Mutual funds	2.09***	1.90***	0.93***
	[42.73]	[35.39]	[17.08]
Leveraged HF – Banks and insurance	2.22***	2.06***	0.92***
	[33.61]	[29.03]	[19.43]
Leveraged HF – Others	1.76***	1.54***	0.82***
	[23.80]	[18.27]	[10.81]

Table X: Cross-sectional regressions of changes in PEV on leveraged hedge fund holdings during the August 2007 quant meltdown

This table reports estimates from cross-sectional regressions of changes in pricing error variance during the quant meltdown in August 2007 on the stock holdings of hedge funds using leverage, holdings of other hedge funds and other types of institutional investors from June 2007. The changes in stock price efficiency are computed between the pre-crisis period June1–June 30 and the crisis period July 15–August 15. The number of observations (stocks) is 3,225. Standard errors are in parentheses below the estimates. Panel B shows tests of the hypothesis that leveraged hedge funds have the same marginal effect on PEV as other types of financial institutions. The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	(1)	(2)	(3)
Intercept	3.02***	2.97***	3.24***
	(0.25)	(0.25)	(0.26)
Leveraged HF hldg.	0.67***	0.69***	0.96***
	(0.22)	(0.22)	(0.21)
Other HF hldg.	0.12	0.08	0.35
	(0.22)	(0.23)	(0.22)
Mutual fund hldg.	-0.10	-0.09	0.09
	(0.08)	(0.08)	(0.10)
Bank and insurance hldg.	0.16	0.16	0.21
	(0.12)	(0.12)	(0.18)
Others hldg.	0.11	0.13	0.33***
	(0.11)	(0.11)	(0.12)
Log of no. of owners	-0.29***	-0.29***	-0.32***
	(0.04)	(0.04)	(0.04)
Lagged PEV	-0.20***	-0.20***	-0.30***
	(0.02)	(0.02)	(0.02)
Short interest ratio	-	-0.02	0.26
	-	(0.22)	(0.16)
Log of total assets	-	0.01	0.02
	-	(0.02)	(0.02)
Book-to-market	-	0.03	0.03
	-	(0.05)	(0.02)
Leverage	-	0.12***	0.07*
	-	(0.05)	(0.04)
Δ Log of standard deviation	-	-	-0.73**
	-	-	(0.33)
Δ Turnover	-	-	-0.04**
	-	-	(0.02)
Δ Effective spread	-	-	1.17***
	-	-	(0.25)
R^2	0.09	0.10	0.21

Panel B: Tests for differences between the effects of leveraged hedge funds and other types of financial institutions on PEV

	(1)	(2)	(3)
Leveraged HF – Other HF	0.55*	0.61*	0.61**
	[2.75]	[3.45]	[3.87]
Leveraged HF – Mutual funds	0.77***	0.78***	0.87***
	[19.35]	[18.35]	[25.10]
Leveraged HF – Banks and insurance	0.51***	0.53***	0.75***
	[7.62]	[6.91]	[14.99]
Leveraged HF – Others	0.56***	0.56***	0.63***
	[9.29]	[8.64]	[11.98]

Table XI: Cross-sectional regressions of changes in alternative measures of price efficiency on changes in institutional holdings

This table shows estimates from cross-sectional regressions of quarterly changes in PEV standardized by the total intraday variance (Std. PEV), 15- to 30-minute variance ratios (VR(15,30)), and 30-minute quote midpoint return autocorrelations (AC(30)) on lagged changes in institutional holdings and control variables. The estimates reported are time series means of quarterly regression slopes from 2000 to 2012. The average number of observations per quarter is 2,671. Standard errors (in parentheses) are computed from the time series of coefficient estimates using the Newey-West procedure with four lags. Panel B shows tests of the hypothesis that hedge funds have the same marginal effect on PEV as other types of financial institutions. The *F*-statistics are in brackets below the coefficient estimates. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Parameter estimates

	Std. PEV	VR(15,30)	AC(30)
Intercept	0.40	0.29	0.11
	(0.31)	(0.20)	(0.09)
Δ Hedge fund hldg.	-2.07***	-0.59***	-0.13***
	(0.34)	(0.16)	(0.04)
Δ Mutual fund hldg.	-0.58***	-0.15***	-0.04***
	(0.15)	(0.03)	(0.01)
Δ Bank and Insurance hldg.	-0.61***	-0.09	-0.08***
	(0.11)	(0.08)	(0.02)
Δ Others hldg.	-0.32*	-0.02	-0.02
	(0.17)	(0.06)	(0.02)
Δ Log of no. of owners	-0.46***	-0.07***	-0.02***
	(0.07)	(0.02)	(0.01)
Lagged efficiency measure	-0.14***	-0.83***	-0.71***
	(0.01)	(0.01)	(0.01)
R^2	0.10	0.44	0.36

Panel B: Tests for differences between the effects of hedge funds and other types of financial institutions on PEV

	Std. PEV	VR(15,30)	AC(30)
HF – Mutual funds	-1.49***	-0.44***	-0.09**
	[16.52]	[7.77]	[4.63]
HF – Banks and insurance	-1.46***	-0.50***	-0.05
	[17.22]	[8.64]	[1.29]
HF – Others	-1.75***	-0.57***	-0.11**
	[21.64]	[12.02]	[6.54]

Table XII: Cross-sectional regressions of changes in PEV on institutional holdings decomposed into changes and last period's levels

This table shows estimates from cross-sectional regressions of quarterly changes in pricing error variance (PEV) on institutional holdings decomposed into changes and last period's levels. The estimates reported are time series means of quarterly regression slopes from 2000 to 2012. The average number of observations per quarter is 2,671. Standard errors (in parentheses) are computed from the time series of coefficient estimates using the Newey-West procedure with four lags. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)
Intercept	-0.06	-0.06	-0.04
	(0.05)	(0.05)	(0.03)
Δ Hedge fund hldg.	-2.30***	-2.07***	-1.73***
	(0.31)	(0.16)	(0.31)
Δ Mutual fund hldg.	-0.49***	-0.28**	-0.12
	(0.16)	(0.13)	(0.13)
Δ Bank and Insurance hldg.	-0.36***	-0.19	-0.11
	(0.13)	(0.12)	(0.08)
Δ Others hldg.	-0.23	-0.12	0.05
	(0.15)	(0.14)	(0.13)
Hedge funds hldg. [t-1]	-0.05	-0.05	-0.03
	(0.04)	(0.04)	(0.03)
Mutual funds hldg. [t-1]	-0.02	-0.01	-0.02
	(0.03)	(0.03)	(0.02)
Bank hldg. [t-1]	-0.06	-0.06	-0.09
	(0.08)	(0.08)	(0.06)
Others hldg. [t-1]	-0.04	-0.03	-0.04
	(0.02)	(0.02)	(0.03)
Δ Firm characteristics	No	Yes	Yes
Δ Liquidity	No	No	Yes
R^2	0.09	0.11	0.33

Table XIII: Regressions of changes in institutional holdings on past changes in efficiency

This table shows slopes from univariate regressions of quarterly changes in institutional holdings on past quarters' changes in stock price efficiency. The regressions are estimated with time fixed effects, and standard errors (in parentheses) are adjusted for clustering by quarter and by firm. All regression slopes are multiplied by 100 for ease of exposition. The superscripts *, ** indicate statistical significance at the 10% and 5% level, respectively.

	Dependent variable			
Explanatory variable	Δ Hedge fund hldg.	Δ Mutual fund hldg.	Δ Bank hldg.	Δ Others hldg.
Δ PEV[t-1]	0.18	-0.05*	-0.08**	-0.03
	(0.21)	(0.03)	(0.03)	(0.02)
Δ Std. PEV[t-1]	0.09	-0.03	-0.04**	0.01
	(0.08)	(0.03)	(0.01)	(0.01)
Δ VR(15,30)[t-1].	0.04	-0.15	-0.09	0.06
	(0.03)	(0.12)	(0.07)	(0.07)
Δ AC(30)[t-1]	0.05	-0.05**	-0.02	-0.01
	(0.07)	(0.02)	(0.01)	(0.01)

Appendix A: Estimation of the PEV measure

The estimation of PEV is based on the method introduced by Beveridge and Nelson (1981) to decompose a non-stationary time series into a random walk component and a stationary component. We follow the procedure suggested by Hasbrouck (1993) and estimate a vector autoregressive (VAR) system with five lags for each firm: [1]

$$r_t = \sum_{k=1}^{5} a_k\, r_{t-k} + \sum_{k=1}^{5} b_k\, x_{t-k} + v_{1,t}$$
$$x_t = \sum_{k=1}^{5} c_k\, r_{t-k} + \sum_{k=1}^{5} d_k\, x_{t-k} + v_{2,t}, \qquad \text{A.1}$$

where r_t is the change in the logarithm of transaction price; x_t is a vector of three trade variables, including the trade sign, the signed trade volume, and the signed square root of the trade volume to allow for nonlinearity; [2] and v_{1t} and v_{2t} are zero-mean, serially uncorrelated disturbances. The VAR is inverted to obtain the vector moving average representation (VMA). The VMA for the log-price change equation can be written as:

$$r_t = \sum_{j=0}^{\infty} a_j^*\, v_{1,t-j} + \sum_{j=0}^{\infty} b_j^*\, v_{2,t-j.} \qquad \text{A.1}$$

Using the identifying assumption that the pricing error is related to information or to one of the trade variables in x, the pricing error (s) is:

$$s_t = \sum_{j=0}^{\infty} \alpha_j\, v_{1,t-j} + \sum_{j=0}^{\infty} \beta_j\, v_{2,t-j.} \qquad \text{A.2}$$

[1] The VAR estimates are not sensitive to the use of different lag structures.

[2] The trade variables and their powers are included to strengthen the estimate of PEV, and the estimates are not sensitive to the choice of trade variables.

where $\alpha_j = \sum_{k=j+1}^{\infty} a_k^*$, and $\beta_j = \sum_{k=j+1}^{\infty} b_k^*$. The magnitude of the pricing error is measured by its standard deviation (σ_S):

$$\sigma_S = \sqrt{\sum_{j=1}^{\infty} [\alpha_j \ \beta_j] Cov(v) [\alpha_j \ \beta_j]'} . \qquad \text{A.4}$$

We refer to the natural logarithm of one plus σ_S multiplied by 100 as PEV. We also divide σ_S by the standard deviation of log transaction prices, and use this ratio expressed in percent as the standardized PEV.