Hedge Fund Holdings and Stock Market Efficiency

Charles Cao
Smeal College of Business, Pennsylvania State University

Bing Liang
Isenberg School of Management, University of Massachusetts

Andrew W. Lo
Sloan School of Management, Massachusetts Institute of Technology
AlphaSimplex Group, LLC

Lubomir Petrasek*
Board of Governors of the Federal Reserve System

We study the relation between hedge fund equity holdings and measures of informational efficiency of stock prices derived from intraday transactions as well as daily data. Our findings support the role of hedge funds as arbitrageurs who reduce mispricing in the market. Hedge funds invest in stocks that are relatively inefficiently priced, and the price efficiency of these stocks improves after hedge funds increase their holdings. Hedge fund ownership contributes more to efficient pricing than ownership by other types of institutional investors. However, stocks held by hedge funds experienced large declines in price efficiency during several liquidity crises. (*JEL* G14, G23)

Received July 27, 2016; editorial decision January 07, 2017 by Editor Wayne Ferson.

Hedge fund ownership of stocks has increased rapidly over the past two decades, in particular prior to the outbreak of the Financial Crisis in 2008.

* We thank an anonymous referee, Reena Aggarwal, Vikas Agarwal, Turan Bali, Stephen Brown, Yong Chen, Jess Cornaggia, Burcu Duygan-Bump, Raphael Douady, Matt Eichner, Jesse Ellis, Wayne Ferson (the Editor), Campbell Harvey, Jean Helwege, David Hirshleifer, Tom King, Chris Schwarz, Nitish Sinha, Jeremy Stein, Zheng Sun, Sheridan Titman, Tugkan Tuzun, Ashley Wang, Jie Yang, Lu Zheng, and seminar and conference participants at the Federal Reserve Board of Governors, Bentley University, Georgetown University, University of Georgia, Imperial College London, North Carolina State University, Texas A&M, UC Irvine, University of Cambridge, University of Connecticut, University of Massachusetts Amherst, University of Melbourne, University of Miami, University of New South Wales, University of Sydney, University of Technology Sydney, University of Warwick, and the 2014 China International Conference in Finance, 2015 AFA Annual Meeting, and 7th Annual Hedge Fund Research Conference in Paris for their valuable comments and suggestions. We thank George Aragon and Philip Strahan for sharing their data on holdings of Lehman-connected funds, and Edward Atkinson and Grant Farnsworth for their excellent research assistance. The analysis and conclusions set forth are those of the authors and do not indicate concurrence by other members of the research staff of the Board of Governors, MIT, AlphaSimplex Group, or any of its affiliates and employees. Send correspondence to Lubomir Petrasek, Board of Governors of the Federal Reserve System, 20th Street and Constitution Avenue N.W., Washington, D.C. 20551, USA, phone: 814-321-7810, email: lubomir.petrasek@frb.gov.

Published by Oxford University Press on behalf of The Society for Financial Studies 2017.
doi:10.1093/rapstu/rax015

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, little is known about the effects of hedge fund ownership on the informational efficiency of stock prices.

Understanding the role of hedge funds in securities markets is important for several reasons. First, 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. Further, because of hedge funds' increased involvement in 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. Finally, the information in stock prices guides investment decisions and therefore the allocation of economic resources and welfare (Tobin, 1969; Dow and Gorton, 1997). If hedge fund trading improves efficiency of the stock market, it will also improve investor welfare by facilitating hedging and risk sharing (Dow and Rahi, 2003).

Boehmer and Kelly (2009) show that institutional investors as a whole increase the informational efficiency of transaction prices of the stocks they hold because they are more sophisticated than individual investors. However, it is important to note that hedge funds differ from other institutional investors in their trading styles, incentives, and use of leverage. As arbitrageurs, hedge funds execute trading strategies that exploit mispricing and may improve stock price efficiency more than the trades of other institutional investors. It is therefore of interest to separate hedge fund trading from non-hedge fund trading when studying the contribution of institutional investors to price discovery. In this paper, we analyze the role of different types of institutional investors, and find that, on average, hedge funds contribute more to stock market efficiency than other institutional investors such as mutual funds or banks and insurance companies. Our findings also indicate that this positive role of hedge funds critically depends on the availability of funding. Using liquidity crisis events as natural experiments, we document that stocks held by hedge funds that were subject to funding shocks experienced greater mispricing during several crisis episodes.

Academic researchers and practitioners have long regarded hedge funds as among the most sophisticated investors—rational arbitrageurs 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 institutional or individual investors. Compared to the managers of mutual funds and other investment companies, hedge fund managers are lightly regulated and 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 (e.g., Cao, Chen et al., 2016; Cao, Goldie et al., 2016), and in many cases act as informed activist investors (e.g., Brav et al., 2008). Recently, Agarwal et al. (2013) and Aragon, Hertzel, and Shi (2013) find that confidential 13F filings by hedge funds can predict future stock returns up to 12 months, and Sias, Turtle, and Zykaj (2016) show that hedge funds' demand shocks are positively related to subsequent returns, supporting the view that hedge funds are informed traders. Akbas et al. (2015) and Kokkonen and Suominen (2015) find that aggregate flows to hedge funds attenuate stock return anomalies, while aggregate flows to mutual funds exacerbate anomalies. Therefore, it is necessary to distinguish the effect of hedge funds on price efficiency from that of other institutional investors such as mutual funds or banks and insurance companies.

On the other hand, hedge funds' quantitative trading strategies and reliance on leverage could destabilize financial markets and reduce price efficiency in some circumstances. 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

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

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 or volatility is high, thus increasing non-fundamental volatility during liquidity crises (e.g., Cao et al., 2013).

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; and examine a lower-frequency measure that captures the speed of adjustment to market-wide information. 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 three measures of price efficiency—return autocorrelations, variance ratios, and the speed-of-adjustment measure—capture patterns in stock returns that are inconsistent with efficient pricing, namely serial dependencies in quote midpoint returns, discrepancies between the variances of long-term and short-term returns, and the delay with which prices respond to information.[2] Since all of the measures are based on intraday or daily returns, they are unlikely to be affected by time-variation in expected returns at low frequencies such as the business cycle, which simplifies the analysis.

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, in particular if the hedge funds are relatively small, trade frequently, and their managers have superior stock picking skills. This finding supports the view that, on average, hedge funds operate as arbitrageurs and contribute to the informational efficiency of prices.

We also compare hedge funds' effect on price efficiency with the effects of other institutional investors, such as mutual funds or banks and insurance companies. We find some evidence that higher ownership by banks and

[2] In the terminology of Fama (1970), return autocorrelations, variance ratios, and the speed-of-adjustment measure capture a weak form of efficiency because their information set includes just historical prices. The information set of the PEV measure is wider, including information from order flow in addition to past prices, making it closer to semi-strong efficiency.

mutual funds is associated with efficiency gains. However, stock acquisitions by hedge funds improve informational efficiency significantly more than do acquisitions by banks or mutual funds. This finding supports the hypothesis that hedge funds contribute 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.

However, we find that hedge funds did not exert a correcting force on stock price efficiency during several liquidity events, most notably in the last quarter of 2008, when stocks held by hedge funds experienced greater subsequent declines in price efficiency. To understand the effect of hedge funds on price efficiency during liquidity crises, we examine the changes in price efficiency around the bankruptcy of Lehman Brothers in September 2008 and during the so-called Quant Meltdown in August 2007. We collect data on the characteristics of hedge funds that held shares prior to the events, including their prime broker, use of leverage, redemption restrictions, and the interaction between redemption restrictions and the use of leverage. Similar to Aragon and Strahan (2012), we find that stocks held by hedge funds using Lehman Brothers as their prime broker experienced greater declines in price efficiency following the bankruptcy of Lehman Brothers than stocks held by other hedge funds and non-hedge fund institutions. In addition, we find that stocks held by leveraged hedge funds were more mispriced following Lehman's bankruptcy than stocks held by hedge funds that do not use leverage, in particular if the leveraged funds impose few restrictions on investor redemptions. These hedge funds were forced to sell more of their stock holdings at a temporarily depressed price, contributing to the mispricing of these stocks. We find similar evidence for stocks held by leveraged hedge funds during the Quant Meltdown in August 2007. Taken together, the findings from the two 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 during liquidity crises.

Several limitations of the study must be noted. First, despite using one of the most comprehensive data sets on institutional holdings, we do not observe the entire portfolio of hedge funds or their trades. Our holdings data is based on quarterly snapshots of hedge funds' long equity positions and the aggregated short positions, which may limit our ability to detect the effect of individual hedge funds' trades on stock price efficiency. A related point is that the relation between the changes in hedge fund holdings and stock price efficiency may be driven by unobserved time-varying characteristics of the stocks, despite our best effort to control for such characteristics. Notwithstanding these limitations, the results in this study have significant implications for several strands of finance research.

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 (2010), Billio et al. (2012), and Brown et al. (2012), and Kang, Kondor, and Sadka (2014), consider the role of hedge funds in spreading financial crises. Brunnermeier and Nagel (2004) and Griffin et al. (2011) analyze hedge funds' holdings of technology stocks during the technology bubble of the late 1990s, and show that hedge funds did not exert a correcting force on stock prices during the bubble period. Other studies such as Brown, Goetzmann, and Park (2010), Agarwal et al. (2013), Kokkonen and Suominen (2015), and Sias, Turtle, and Zykaj (2016) support a positive role of hedge funds during crises and on average. We contribute to this debate by showing that hedge funds' impact on equity market efficiency, though generally positive, can become negative during liquidity crises.

More broadly, our paper adds to the body of literature on the role of institutional investors in the stock market. The paper closest to ours is Boehmer and Kelly (2009), who study the relation between the aggregate institutional holdings and informational efficiency of prices. We extend this research by comparing the roles played by specific types of institutions, such as hedge funds, mutual funds, and banks. Other recent studies of the effect of institutional investors on financial markets include Yan and Zhang (2009), Lewellen (2011), Manconi, Massa, and Yasuda (2012), Cao and Petrasek (2014a, 2014b), and Edelen, Ince, and Kadlec (2016). Our results add to this literature by showing 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 1 presents summary statistics for several measures of informational efficiency; Section 2 presents data on hedge fund equity holdings and other ownership variables; Section 3 presents sample characteristics and control variables; Section 4 analyzes the effect of hedge fund ownership on informational efficiency; and Section 5 offers concluding remarks.

1. 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 and a lower-frequency measure from daily returns. 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. The information set for most of the measures includes just historical prices, akin to the weak form of efficiency in the terminology of Fama (1970). However, our main efficiency measure is based on a wider information set, including information from order flow. Since all of our efficiency measures use intraday or daily returns, they are unlikely to be affected by time-variation in expected returns at low frequencies such as the business cycle.

Our main measure of price efficiency is pricing error variance (PEV), first proposed by Hasbrouck (1993) and used, for example, by Boehmer and Kelly (2009) and Boehmer and Wu (2013). PEV relies on 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.[3] Pricing errors are identified as 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 per month, and obtain monthly estimates of PEV. 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 the Appendix. We refer to the natural logarithm of one plus the pricing error standard deviation multiplied

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

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 the difference in log transaction prices as a control variable in multivariate tests. We also divide the standard deviation of pricing errors by the standard deviation of the difference in log transaction prices, and use this ratio expressed in percent as the standardized PEV.

In addition to PEV, we compute two alternative high-frequency 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.[4] 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 ${\sigma^2}_{15}$ and ${\sigma^2}_{30}$ 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 of the above measures are estimated at the monthly frequency using intraday data.

Finally, we estimate from daily returns a lower-frequency measure of informational efficiency similar to that proposed by Hou and Moskowitz (2005).[5] The Hou-Moskowitz (HM) measure captures the delay with which a stock responds to market information, as represented by the market index.

4 See Ronen (1997) for a survey.

5 Hou and Moskowitz (2005) estimate the measure at the annual frequency from weekly returns. We follow Boehmer and Wu (2013) to estimate the HM measure at the monthly frequency from daily returns. We also replicate the annual measure and find that its cross-sectional correlation with the average monthly measure is 0.54.

In each month, we run a regression of each stock's daily returns on contemporaneous and lagged returns on the CRSP value-weighted portfolio:

$$r_t = \alpha + \beta R_{m,t} + \sum_{n=1}^{5} \delta_n R_{m,t-n} + \varepsilon_{t,} \tag{3}$$

where r_t is the daily stock return and $R_{m,t}$ is the return on the CRSP value-weighted market index on day t. If the stock responds with delay to market information, some of the coefficients δ_n will differ significantly from zero. We also estimate a second regression that restricts all coefficients δ_n to zero, and compute the HM measure as one minus the ratio of the R^2 from the restricted regression over the R^2 from the unrestricted regression in equation (3).

Panel A of Table 1 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 shows the time series averages of these statistics for the entire period from 2000 to 2012 and for three subperiods. 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 2007–2009 financial crisis and it peaked in September 2008. The mean of the standardized PEV is 3.32, and the means of the variance ratio, autocorrelation, and HM measures are 0.38, 0.16, and 0.31, respectively.

Although the five measures capture different dimensions of efficiency and use different sets of information (intraday returns for autocorrelations and variance ratios, returns and order flow for the PEV measures, and daily stock and market returns for the HM measure), they are significantly correlated in both time-series and cross-section. Their cross-sectional correlations range from 0.15 to 0.91, suggesting that the measures capture some common aspects of informational efficiency. For example, the average correlation between the high-frequency PEV measure and the lower-frequency HM measure is 0.35 in the cross-section of stocks.

2. 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

Table 1
Summary statistics

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
HM measure	0.31	0.24	0.25	0.38	0.34	0.22
Panel B. Institutional holdings						
Bank and insurance hldg.	0.14	0.14	0.04	0.13	0.15	0.13
Mutual fund hldg.	0.32	0.32	0.06	0.31	0.32	0.34
Hedge fund hldg.	0.07	0.05	0.04	0.03	0.08	0.09
Others hldg.	0.12	0.11	0.04	0.09	0.12	0.14
No. of non-hedge fund investors	155	98	19.90	152	149	164
No. of hedge fund investors	20	22	12.37	11	21	26
Panel C. 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

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. *HM measure* is the measure of price delays proposed by Hou and Moskowitz (2005). 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.

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).[6]

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

[6] We address the exclusion of short positions from 13F reporting by collecting data on the aggregate short interest for each stock and using it as a control variable in regressions. The short interest data allows us to distinguish between the effects of short-selling and hedge fund ownership on stock price efficiency.

classification 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.[7] 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

[7] 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.

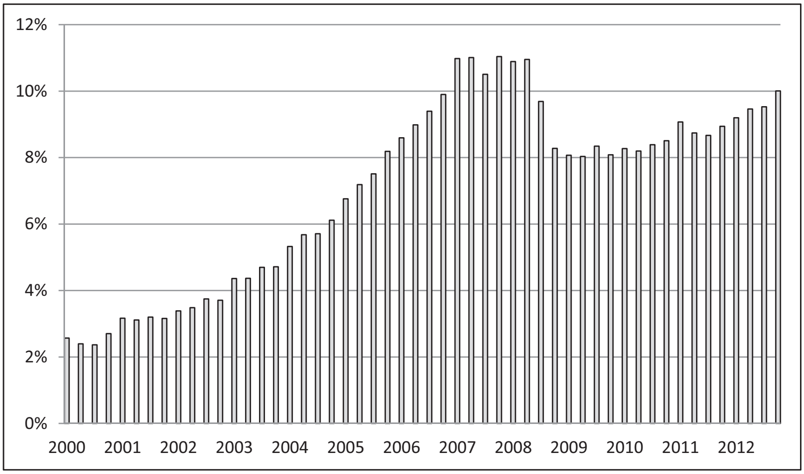

Figure 1
Percentage of shares held by hedge funds
This figure plots the average percentage of shares held by hedge funds for the sample stocks over the 2000:Q1–2012:Q4 period. Sample stocks are listed on NYSE, AMEX, or NASDAQ. Institutional ownership data come from 13F reports. We classify 1,594 filers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

funds, and (3) others.[8] The category "others" includes non-hedge fund investment advisers, foundations, endowments, and private pension funds. The classifications are based on the Thomson Reuters type codes extended by Brian Bushee.[9] As Panel B in Table 1 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

[8] Although commercial banks in the U.S. are generally prohibited from holding common stock in nonfinancial corporations, there are a number of exceptions to this rule, including holdings in financially distressed firms. Bank equity holdings reported in form PF also include trust department holdings over which banks exercise investment discretion.

[9] Since institutional classifications from Thomson Reuters are not reliable after 1998, we use the codes as extended by Brian Bushee. We thank Brian Bushee for making the data available on his website: http://acct.wharton.upenn.edu/faculty/bushee/IIclass.html.

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

3. Sample Characteristics and Control Variables

Our sample comprises 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 because of differences in financial reporting. 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. Boehmer, Huszar, and Jordan, 2010; 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 of a stock to the number of outstanding shares.[10] We compute all measures on a monthly basis, contemporaneously with measures of price efficiency.

Panel C of Table 1 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.

4. Empirical Analysis

4.1. The characteristics of hedge funds' equity holdings

Before examining the effects of hedge fund ownership on market efficiency, we provide a detailed analysis of hedge funds' end-of-quarter equity holdings to examine the ex-ante characteristics and price efficiency of the stocks that are preferred by hedge funds. Table 2 reports the summary statistics for our sample stocks sorted into terciles based on the percentage of outstanding shares held by hedge funds at the end of each quarter (q). 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 2 reports the ex-ante efficiency measures for the portfolios sorted by subsequent hedge fund ownership. The measures reveal that hedge funds tend to hold stocks that were priced relatively inefficiently in quarter q. 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, higher autocorrelations, and longer price delays than stocks in the low hedge fund ownership portfolio, suggesting that hedge funds have a preference for less efficiently priced stocks.

[10] As an alternative turnover measure, we also use the portfolio turnover of institutional investors holding a stock, weighted by the investors' share holdings. The results are qualitatively similar.

Table 2
Summary statistics sorted by end-of-quarter hedge fund holdings

Variable	Hedge fund ownership tercile (end-of-quarter)			High–Low
	Low	Medium	High	
Panel A. Measures of price efficiency				
Pricing error variance (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**
HM measure	0.29	0.30	0.34	0.05***
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

This table reports summary statistics for portfolios of stocks sorted quarterly into terciles by the end-of-quarter hedge fund holdings. Stock characteristics and price efficiency are measured during the previous quarter. The columns show time series averages of the statistics 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.

Panel B reports other characteristics of stocks held to a greater extent by hedge funds have greater short interest ratios than stocks that are held to a lesser extent by hedge funds. The companies in which hedge funds invest more 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 2 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 (e.g., Brunnermeier and Nagel, 2004).

4.2. Changes in hedge fund holdings and price efficiency

4.2.1. 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. In this section, we examine whether the price efficiency of the stocks changes subsequent to increases and decreases 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, and 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 quarters of 2008.

Stocks with an increased hedge fund ownership become closely followed by hedge funds, who may buy more shares or sell their holdings if prices converge to the estimated fundamental value. Indeed, these stocks are likely to be traded again by hedge funds over the subsequent quarter. As the bottom panel of Table 3 shows, 36% of the stocks in the "Buy" hedge fund portfolio in quarter q are in the "Buy" portfolio again in quarter $q+1$, while 33% are in the "Sell" portfolio. 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 $q+1$.[11] Since our focus is on cross-sectional variations in price efficiency rather than on time-series variations, we de-mean the changes in efficiency in each quarter.

Table 3 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. This finding

[11] 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).

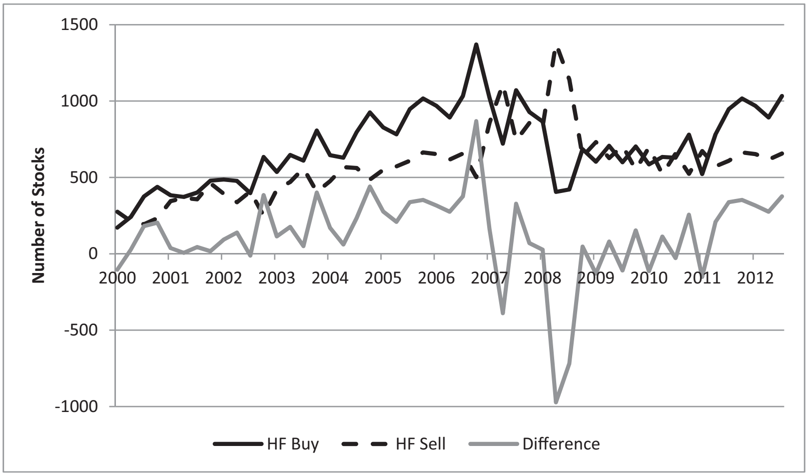

Figure 2
Number of stocks bought and sold by hedge funds
This figure depicts the number of stocks in portfolios sorted according to quarterly changes in hedge fund ownership from 2000 to 2012. Portfolio "Buy" includes stocks for which hedge funds increase their holdings by more than 1% of shares outstanding 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" portfolios.

Table 3
Changes in informational efficiency following changes in hedge fund holdings

Δ Efficiency measure (q+1)	Change in hedge fund holdings (q)			Buy–Sell
	Sell	No change	Buy	
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***
HM measure	0.006	0.001	−0.020***	−0.026***
% 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	

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 bottom panel 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.

supports the hypothesis that increased hedge fund ownership leads to improved price efficiency. There is no corresponding significant decline in efficiency among stocks with decreased hedge fund ownership, perhaps because hedge funds sell these stocks only after their initial mispricing is corrected.

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, return autocorrelations, and price delays 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 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 4 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. Note that PEV is the only measure that is significant regardless of the size quartile. As a robustness test of this result, we first sort stocks into terciles based on the changes in hedge fund holdings and then on size. The finding that changes in hedge fund holdings have a larger effect on small and medium-capitalization stocks remains unchanged.

We further explore how the changes in holdings of institutions other than hedge funds affect price efficiency. Table 5 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. Once again, PEV is the strongest measure among all the inefficiency measures. 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.

Table 4
Changes in informational efficiency by firm size

Δ Efficiency measure (q+1)	Change in hedge fund holdings (q)			Buy–Sell
	Sell	No change	Buy	
		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***
HM measure	0.011	−0.001	−0.036***	−0.047***
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*
HM measure	0.005	0.005	−0.021**	−0.026**
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
HM measure	0.006	−0.001	−0.011	−0.017*
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
HM measure	0.003	−0.001	−0.011	−0.014
Avg. no. of stocks per quarter	101	445	123	

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.

4.2.2. 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. Are these efficiency improvements brought about by hedge funds' trades or do they reflect changes that are unrelated to hedge fund holdings, such as mean reversion in efficiency measures or changes in stock characteristics? A definitive answer to this question would require that hedge funds purchase and sell stocks at random. In practice, hedge funds have a preference for stocks with certain characteristics and level of efficiency. To partially address this issue, we conduct a firm-level analysis which controls for the lagged level of efficiency and changes in the observable stock characteristics. The analysis at the firm level also allows us to compare

Table 5
Changes in informational efficiency following changes in mutual fund holdings

Δ Efficiency measure (q+1)	Change in mutual fund holdings (q)			Buy–Sell
	Sell	No Change	Buy	
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*
HM measure	0.001	0.007	−0.005	−0.006
% 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	

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 bottom panel 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.

the effect of hedge funds on informational efficiency with the effects of other types of institutional investors. In each quarter q, we estimate the following cross-sectional regression:

$$\begin{aligned}\Delta IE_{i,q} =& \beta_0 + \beta_1{}'\Delta IO_{i,q-1} + \beta_2{}'\Delta CHAR_{i,q-1} + \beta_3{}'\Delta V\&L_{i,q} \\ &+ \beta_4 IE_{i,q-1} + \varepsilon_{i,q},\end{aligned} \tag{4}$$

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.[12] 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

[12] 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.

changes from the previous quarter.[13] In addition, the regression includes the lagged level of the efficiency measure to account for a possible mean reversion—that is, the possibility that fund managers buy mispriced stocks that tend to revert to their normal efficiency level even without the funds' intervention. Inferences are conducted from the time series of coefficient estimates using the Fama-MacBeth (1973) methodology, and the significance of the coefficient estimates is assessed based on heteroskedasticity and autocorrelation robust standard errors.

Column (1) in Table 6 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 and the lag of the efficiency measure. 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, indicating that hedge funds' activity reduces mispricing during most of the sample period.

The 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. However, other 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 6 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 6 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 evidence in Boehmer and Kelly (2009) 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 6 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

[13] Boehmer and Kelly (2009) use the level of institutional holdings instead of the changes. We estimate the model in first differences to eliminate unobservable heterogeneity across stocks. As we show in the robustness section of the paper, the results based on levels are qualitatively similar.

Table 6
Cross-sectional regressions of changes in PEV on changes in institutional holdings

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 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]

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.

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., Boehmer, Huszar, and Jordan, 2010; Saffi and Sigurdsson, 2010; Boehmer and Wu, 2013).

Volatility and liquidity are related but distinct concepts from informational efficiency. In the last specification in Table 6, we include contemporaneous changes in intraday volatility, turnover, and bid-ask spreads among the control variables. Including volatility and liquidity measures improves the fit of the model considerably, and the R^2 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.

4.3. Hedge fund characteristics and price efficiency

Given the positive relation between changes in hedge fund holdings and stock price efficiency, an important and yet unanswered question is how the efficiency improvements arise. One possibility is that the changes in ownership capture the degree of trading activity in a stock by skilled or informed hedge fund managers. If this hypothesis is correct, the improvements in efficiency should be associated with hedge fund characteristics such as portfolio turnover, fund manager skills, or fund size.

To test these hypotheses, we analyze holdings of different types of hedge funds, including those with different sizes, turnover rates, and fund manager skills, and their relation with stock price efficiency.[14] In each quarter, we

[14] We thank an anonymous referee for suggesting these tests.

classify hedge fund management firms in two types (below or above median) by sorting on the value of each characteristic in the previous two years, and calculate the holdings of hedge funds with different characteristics. Size is measured by the market value of portfolio holdings reported by each asset manager in Form 13F. Portfolio turnover is measured as the dollar value of securities bought or sold—whichever is less—divided by the portfolio value at the beginning of each quarter. This definition of turnover captures trades that are motivated by a decision to rebalance rather than those that are driven by inflows and outflows. Fund manager skill is measured in two alternative ways: (1) using the performance measure proposed by Grinblatt and Titman (1993) (the "GT measure"), which is based on the covariance between portfolio weight changes and the subsequent realized returns; and (2) using the measure of selectivity skills proposed by Ferson and Mo (2016), which is based on the covariance between portfolio weights and subsequent risk-adjusted returns. Whereas the GT performance measure could be higher for managers who systematically include in their portfolios stocks when their expected returns are higher than usual, the selectivity skill measure is unaffected by such timing and captures only the managers' security selection skills.[15] We estimate both measures at the quarterly frequency and average them over the past two years to reduce noise. The GT measure does not require the specification of a benchmark portfolio, effectively using the performance of the static portfolio held by the fund in quarter *q*–1 as a benchmark; the selectivity skill measure is estimated using the Carhart (1997) four-factor model as the benchmark.[16] The median fund portfolio size is $291 million on average over the sample period; the median annualized turnover is 143%; the median annualized GT performance measure is 58 basis points; and the median annualized selectivity skill measure is 46 basis points.

Panel A of Table 7 provides summary statistics for the holdings of Type 1 (below-median) and Type 2 (above-median) hedge funds according to their size, turnover, fund manager performance, and selectivity. Small hedge funds hold 1% of the outstanding shares on average, while large hedge funds hold 6.4%. The holdings sorted on turnover, GT measure, and selectivity skills are more equally balanced between the two types of funds.

Panel B of Table 7 shows the results of tests for differences between the effects of the two fund types on stock price efficiency based on the specification (2) in Table 6. The table reveals that smaller funds reduce mispricing by more than larger funds, and the difference is significant at the 5% level

[15] The selection measure developed by Ferson and Mo (2016) improves on the characteristics selectivity measure proposed by Daniel et al. (1997) by allowing for both market and volatility timing as well as stock picking in a consistent framework.

[16] We follow Ferson and Mo (2016) and estimate the factor betas of the individual securities held using the past year of daily data for the stocks and the benchmarks. Market-wide parameters are estimated using 36 months of data on the benchmarks. The selectivity measure is computed for the subsequent quarter using the previous quarter's asset allocation weights and the ex-post abnormal returns.

Table 7
The effects of different types of hedge funds on PEV

Panel A. Holdings of different types of hedge funds

Type 1 hedge funds	Type 2 hedge funds	Type 1 holdings	Type 2 holdings
Small size	Large size	1.0%	6.4%
High turnover	Low turnover	2.8%	4.6%
High GT measure	Low GT measure	4.2%	3.1%
High selectivity skill	Low selectivity skill	3.9%	3.4%

Panel B. Tests for differences between the effects of different types of hedge funds on PEV

Type 1 hedge funds	Type 2 hedge funds	Type 1 coeff.	Type 2 coeff.	Difference	*F*-statistic
Small	Large	−2.56***	−1.2***	−1.36**	7.07
High turnover	Low turnover	−2.54***	−0.43***	−2.11***	21.28
High GT measure	Low GT measure	−2.08***	−1.25***	−0.83**	5.37
High selectivity skill	Low selectivity skill	−2.58***	−1.42***	−1.16**	6.11

This table examines the effects of different types of hedge funds on PEV. Panel A reports the percentage of outstanding shares held by hedge funds that are classified in each quarter in two types (Type 1 is below the sample median, Type 2 is above the sample median) based on the lagged portfolio size, turnover, the Grinblatt and Titman (1993) measure of fund manager performance ("GT measure"), and the selectivity skill measure of Ferson and Mo (2016). Panel B reports the coefficient estimates for the different types of hedge funds based on specification (2) in Table 6, and the *F*-test for the difference in the estimated coefficients between Type 1 and Type 2 hedge funds. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

(*F*-statistic=7.07). This finding is consistent with the view that smaller hedge funds are more likely to be informed than larger funds. Furthermore, high-turnover funds reduce the PEV significantly more than low-turnover funds (*F*-statistic=21.28), showing that fund trading is the primary means through which hedge fund holdings affect price efficiency. Finally, the holdings of highly skilled funds are associated with a significantly greater reduction in mispricing than the holdings of less skilled funds, regardless of the measure of skill. Both measures show that the efficiency improvements are more strongly associated with holdings by hedge fund managers with demonstrated skills. This finding is consistent with the hypothesis that skilled hedge fund managers reduce mispricing by incorporating information into stock prices.

4.4. Event Studies of Liquidity Crises

The estimated effect of hedge fund ownership on PEV in column (1) of Table 6 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 changes sign in the fourth quarter of 2008 and when the dot-com bubble burst in the second quarter of 2000. Interestingly, the periods when greater hedge fund holdings are associated with lower price efficiency coincide with elevated levels of the TED spread—a measure of funding conditions—in particular during the 2007–

2009 financial crisis.[17] This finding suggests that the effect of hedge fund ownership on price efficiency depends on funding liquidity.

4.4.1. The bankruptcy of Lehman Brothers. The bankruptcy of Lehman Brothers on September 15, 2008, marks the largest liquidity event during the sample period as measured by the TED spread. We examine in an event-study framework the effect of hedge fund holdings on price efficiency during Lehman's bankruptcy. To test the hypothesis that changes in price efficiency during liquidity crises depend on ownership by hedge funds, we estimate the following cross-sectional regression:

$$\Delta IE_{i,t} = \gamma_0 + \gamma_1{}' IO_{i,t-1} + \gamma_2{}' CHAR_{i,t-1} + \gamma_3{}' \Delta V\&L_{i,t} + \gamma_4 IE_{i,t-1} + \varepsilon_{i,t}, \tag{5}$$

where $\Delta IE_{i,t}$ is the change in informational efficiency of stock i between the pre-crisis period August 1–August 31 and the crisis period September 15–October 15. The vector $IO_{i,t-1}$ contains the ownership fractions of institutional investors, including hedge funds, mutual funds, banks, and others, reported prior to the bankruptcy event on June 30, 2008. The other explanatory variables remain the same as in equation (4). However, rather than use the changes in institutional ownership and stock characteristics as explanatory variables, we use the *levels* of institutional ownership (IO) for the event study because levels better reflect the amount of shares that institutions could be forced to sell during the crisis. For example, as shown in Figure 1, hedge fund holdings on average fell by 28% of their June 30, 2008 level by December 31, 2008. Therefore, we use the pre-crisis level of hedge funds holdings (and the holdings of different types of hedge funds) as a proxy for subsequent forced selling by hedge funds. Stock characteristics ($CHAR$) are also measured as levels.

Table 8 provides the estimated coefficients (γ) and t-statistics from equation (5). 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, indicating an adverse effect on price efficiency. As shown in Panel B or Table 8, the difference between the effects of hedge funds and other financial institutions is significant, showing that stocks held by hedge funds experienced larger increases in mispricing during Lehman's bankruptcy than stocks held by other investor types.

Next, we examine the channels through which hedge fund holdings may have adversely affected price efficiency following Lehman's bankruptcy.

[17] We measure TED spread as the difference between the 3-month LIBOR and the 3-month Treasury bill interest rate. Other measures of market-wide funding conditions, such as the LIBOR-OIS spread, measured as the difference between the 3-month LIBOR and the overnight index swap rate, increase during the same period.

Table 8

Cross-sectional regressions of changes in PEV on hedge fund holdings following Lehman's bankruptcy

Panel A. Parameter estimates

	(1)	(2)	(3)
Intercept	4.52***	4.41***	3.66***
	(0.38)	(0.38)	(0.37)
Hedge fund hldg.	0.97***	0.93***	0.44***
	(0.22)	(0.22)	(0.13)
Mutual fund hldg.	−0.44***	−0.41***	−0.21**
	(0.11)	(0.13)	(0.09)
Bank and insurance hldg.	−0.56*	−0.56*	−0.12
	(0.29)	(0.29)	(0.29)
Others hldg.	−0.11	−0.05	−0.19
	(0.22)	(0.22)	(0.16)
Log of no. of owners	−0.25***	−0.25***	−0.15***
	(0.05)	(0.05)	(0.05)
Lagged PEV	−0.34***	−0.34***	−0.31***
	(0.03)	(0.03)	(0.04)
Short interest ratio	–	−0.31	−0.39*
	–	(0.24)	(0.20)
Log of total assets	–	0.01	0.02
	–	(0.02)	(0.02)
Book-to-market	–	0.12***	0.05***
	–	(0.04)	(0.02)
Leverage	–	0.25***	0.21***
	–	(0.10)	(0.08)
Standard deviation	–	–	−0.63
	–	–	(0.60)
Turnover	–	–	−0.02
	–	–	(0.02)
Effective spread	–	–	0.73***
	–	–	(0.11)
R^2	0.21	0.23	0.25

Panel B. Tests for differences between the effects of hedge funds and other types of financial institutions on PEV following Lehman's bankruptcy

	(1)	(2)	(3)
Hedge Funds – Mutual funds	1.41***	1.34***	0.65***
	[44.27]	[40.26]	[16.66]
Hedge Funds – Banks and insurance	1.53***	1.49***	0.56***
	[25.59]	[24.39]	[5.98]
Hedge Funds – Others	1.08***	0.98***	0.63***
	[16.01]	[13.33]	[9.86]

This table reports estimates from cross-sectional regressions of changes in pricing error variance (PEV) following the bankruptcy of Lehman Brothers on the stock holdings of hedge funds in June 2008, 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 hedge funds had the same marginal effect on PEV following Lehman's bankruptcy 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.

Some hedge funds that used Lehman Brothers as their prime broker had their collateral tied up in the bankruptcy proceedings, limiting their ability to execute trades. These funds also suffered a significant funding shock when they lost access to prime brokerage financing. As reported by Aragon and Strahan

Table 9

The effects of different types of hedge funds on PEV following Lehman's bankruptcy

Panel A. Holdings of different types of hedge funds as of June 30, 2008

Type 1 hedge funds	Type 2 hedge funds	Type 1 holdings	Type 2 holdings
Lehman	Non-Lehman	1.1%	9.9%
Leveraged	Non-leveraged	4.9%	6.1%
Short notice period	Long notice period	3.3%	7.7%
No lockup	Lockup	4.3%	6.6%
Leveraged short notice	Leveraged long notice	1.5%	3.4%
Leveraged no lockup	Leveraged lockup	1.4%	3.5%

Panel B. Tests for differences between the effects of different types of hedge funds on PEV following Lehman's bankruptcy

Type 1 hedge funds	Type 2 hedge funds	Type 1 coeff.	Type 2 coeff.	Difference	*F*-statistic
Lehman	Non-Lehman	2.19***	0.75***	1.44**	4.68
Leveraged	Non-leveraged	1.5***	0.41	1.09*	3.25
Short notice period	Long notice period	0.52	1.04***	−0.52	0.97
No lockup	Lockup	0.58	1.09***	−0.51	0.99
Leveraged short notice	Leveraged long notice	2.87***	1.27**	1.60**	4.70
Leveraged no lockup	Leveraged lockup	2.66***	1.28**	1.38*	3.22

This table examines the effects of different types of hedge funds on PEV following the bankruptcy of Lehman Brothers. Panel A shows the percentage of outstanding shares held as of June 30, 2008 by hedge funds that are classified in each quarter in two types (Type 1 and Type 2) based on their asset-weighted characteristics. *Lehman* funds are the funds that used Lehman Brothers as their prime broker as of June 30, 2008. *Leveraged* funds report using leverage to hedge fund databases prior to June 2008. *Short notice period* funds have a redemption notice period shorter than 40 days, and *No lockup* funds do not impose initial lockup restrictions on their investors. The holdings of funds that cannot be found in any of the databases are aggregated with Type 2. Panel B reports the coefficient estimates for different types of hedge funds based on specification (2) in Table 8, and the *F*-test for the difference in the estimated coefficients between Type 1 and Type 2 hedge funds. The superscripts *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

(2012), Lehman-connected hedge funds experienced higher bankruptcy rates and the stocks held by these funds became highly illiquid following Lehman's bankruptcy. Following Aragon and Strahan, we examine whether an increase in mispricing of hedge fund holdings in the aftermath of Lehman's bankruptcy reflects the funding problems of Lehman-connected funds. Panel A in Table 9 reports the summary statistics for the holdings of different types of hedge funds as of June 30, 2008, and shows that Lehman-connected hedge funds held 1.1% for the average sample stock.[18]

According to Brunnermeier and Pedersen (2009), the selling pressure caused by de-leveraging of financial institutions can increase mispricing during liquidity crises. Many hedge funds leverage their investments, typically through short-term funding, which could lead to such de-leveraging cycles. On the contrary, a large number of hedge funds do not employ leverage, and limit their investments to their capital. Even these funds could be forced to sell securities in a crisis to meet investor redemptions. However, the selling

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

pressure caused by funds that invest only their investors' capital would be smaller than that caused by de-leveraging cycles. We therefore examine whether ownership by leveraged hedge funds resulted in a greater mispricing following Lehman's bankruptcy than ownership by other hedge funds.

We proceed to separate hedge fund holdings according to the funds' use of leverage. 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, we identify in the databases unique names of all live, equity-oriented hedge funds, and obtain information on their reported use of leverage. If available (TASS, HFR, CISDM), we use a version of each database from June 2008 or before to look up information on leverage. We do not 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 assets under management (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.[19] 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.

Based on the asset-weighted leverage, we identify 288 leveraged hedge fund firms as of June 2008. As shown in Panel A of Table 9, these firms held 4.9% of the outstanding shares for the average sample stock in June 2008, whereas firms that do not use leverage and firms that cannot be accurately classified because they do not report leverage to a database held 6.1%. Notably, leveraged hedge fund holdings declined by 36% of their June 2008 level by the end of the year, while the holdings of other hedge funds decreased by only 22%, suggesting that de-leveraging accounts for a substantial part of the decline in the aggregate hedge fund holdings.

In addition to leverage, a lack of restrictions on fund redemptions such as a short redemption notice period and the absence of lockup restrictions could increase the need to sell assets at fire sale prices. Using the same procedure as

[19] Since institutional holdings are reported at the company level, the distribution of individual hedge fund holdings among funds that are managed by multi-fund companies cannot be observed directly. We therefore assume in this section that the holdings are distributed among the equity-oriented funds of a given company in proportion to the funds' AUM.

for leverage, we aggregate to the fund manager level the redemption notice period length (in days) and an indicator for whether the fund imposes lockup restrictions. We classify managers with redemption notice periods of less than 40 days (the sample median) as having a short notice period, and those with less than 50% of their AUM locked up (72% of hedge fund firms) as having no lockups. Because redemption restrictions may interact with leverage—the degree of forced de-leveraging is likely to be most severe among funds that are simultaneously exposed to redemptions from their investors—we examine the effect of redemption restrictions separately for leveraged and non-leveraged fund managers. As further shown in Panel A of Table 9, the holdings of leveraged fund management firms with short redemption notice periods (1.5% of the outstanding shares) are small compared to those of leveraged managers with long notice periods (3.4% of the outstanding shares), indicating that most leveraged funds impose redemption restrictions. The holdings of leveraged managers without lockup restrictions are also comparatively small. However, the holdings of leveraged fund managers with short redemption notice periods declined by 41% from 2008:Q2 to 2008:Q4, and the holdings of leveraged managers with no lockup restrictions declined by 38%, indicating that both of these manager types were exposed to the combined effects of de-leveraging and investor redemptions.

Panel B in Table 9 reports tests for differences between the effects of the different types of hedge funds on PEV following Lehman's bankruptcy. The tests are based on specification (2) in Table 8, where hedge fund holdings are subdivided according to their characteristics. Notably, equity holdings by Lehman-connected hedge funds have a significantly greater effect on PEV than holdings by other hedge funds (F-statistic=4.68). These results are consistent with Aragon and Strahan (2012), and show that the price efficiency of the stocks held by hedge funds whose access to funding was interrupted as a result of the bankruptcy of Lehman Brothers was adversely affected by the incident. The table also provides some evidence that stocks that were largely held by leveraged funds became more mispriced following Lehman's bankruptcy than other stocks, although the difference is only marginally significant (F-statistic=3.25). Overall, these findings support the hypothesis that hedge fund de-leveraging had an adverse effect on price efficiency during the Lehman crisis.

As further shown in Panel B of Table 9, the differences between the effects of funds with different redemption notice periods and lockup restrictions are not statistically significant. Somewhat surprisingly, the holdings of funds with long notice periods and lockup restrictions are positively related to mispricing, although their effect on mispricing is not significantly different from that of funds with more lenient redemption terms. However, many funds with redemption restrictions use leverage, while those without restrictions do not. The results change if we condition on the use of leverage. Among leveraged funds, short redemption notice periods (F-statistic=4.70) and the absence of lockup restrictions (F-statistic=3.22) are associated with increased mispricing. These findings indicate that leverage and the absence of restrictions on investor redemptions interact to increase the likelihood of fire-sales during liquidity crises with an adverse effect on price efficiency.

4.4.2. Quant meltdown in August 2007. In addition to the bankruptcy of Lehman Brothers, we examine the changes in stock price efficiency around the so-called 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 de-leveraging policies among leveraged equity-oriented hedge funds and resulting in fire sales and mispricing. We examine whether changes in stock price efficiency between the pre-crisis period from June 1–June 30, 2007, and the crisis period from July 15–August 15, 2007, are related to the holdings of hedge funds or certain types of hedge funds.

Quantitative hedge funds typically employ substantial leverage to enhance returns on strategies that on an unlevered 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 up to the August 2007 meltdown so as to maintain the level of returns that investors have come to expect. 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 levered hedge fund companies held 4.5% of the outstanding shares for the average sample stock in June 2007, whereas other hedge fund companies held 6.2%.

Likely because the dislocations were short-lived and limited to quantitative equity-oriented strategies that use leverage, our tests fail to find a significant adverse effect of the overall hedge fund ownership on the changes in price efficiency. The coefficient on hedge fund holdings in the aggregate is insignificant at any conventional level. However, we find a positive relation between changes in mispricing and leveraged hedge fund holdings, significant at the 1% level, and a marginally significant difference between leveraged hedge funds and other hedge funds (F-statistic=3.45). Considering that quant hedge funds are among those using leverage, the results support the hypothesis that the quant meltdown of 2007 increased the mispricing of stocks held by quant hedge funds.

4.5. Robustness analysis

In this section, we examine the sensitivity of the findings to alternative measures of price efficiency and turnover, and consider alternative regression specifications. We also analyze the significance of the effects of hedge fund ownership across different sub-samples, and 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 four alternative measures of price efficiency: (1) the ratio of PEV to the total realized intraday variance (standardized PEV), (2) the ratio of 15- to 30-minute variance of stock returns, (3) the autocorrelation of 30-minute stock returns, and (4) the HM measure of price delays. While the four 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 10 reports the baseline regression results for the four 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). The effect on the long-term efficiency measure of Hou and Moskowitz (2005) is also significantly negative but its magnitude is 0.5 standard deviations (−0.28*0.04/0.25). Also, as Panel B of Table 10 reports, changes in hedge fund holdings typically have a larger effect on these efficiency measures than changes in the holdings of mutual funds or other types of financial institutions.

We also consider an alternative turnover measure as a control variable. Rather than measure turnover by the ratio of a stock's total trading volume to the number of outstanding shares, we focus on the turnover in institutional investors' portfolios. Specifically, we measure a stock's turnover by the share holdings-weighted portfolio turnover of the institutions holding the stock. The portfolio turnover is measured as the dollar value of 13F securities bought or sold—whichever is less—divided by the portfolio value at the beginning of each quarter. Similar to the overall turnover measure, the portfolio turnover of institutional investors is significantly negatively related to PEV, indicating that turnover is one of the major channels through which institutional investors improve price efficiency. The conclusions regarding the effects of different types of investors on price efficiency are essentially the same as those in column (3) of Table 6 if we use the alternative turnover measure. Most types of institutional investors improve price efficiency through their effect on turnover and other liquidity metrics; however, the positive effect of hedge fund investors on price efficiency is not subsumed by the liquidity and turnover effects.

We next consider alternative specifications for the regression tests. According to equation (4), all variables in Table 6 are measured as changes from the previous quarter. Following the approach of Boehmer and Kelly

Table 10

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

Panel A. Parameter estimates

	Std. PEV	VR(15,30)	AC(30)	HM
Intercept	0.40	0.29	0.11	0.01
	(0.31)	(0.20)	(0.09)	(0.04)
Δ Hedge fund hldg.	−2.07***	−0.59***	−0.13***	−0.28***
	(0.34)	(0.16)	(0.04)	(0.05)
Δ Mutual fund hldg.	−0.58***	−0.15***	−0.04***	−0.02
	(0.15)	(0.03)	(0.01)	(0.02)
Δ Bank and Insurance hldg.	−0.61***	−0.09	−0.08***	−0.01
	(0.11)	(0.08)	(0.02)	(0.04)
Δ Others hldg.	−0.32*	−0.02	−0.02	0.01
	(0.17)	(0.06)	(0.02)	(0.03)
Δ Log of no. of owners	−0.46***	−0.07***	−0.02***	−0.03***
	(0.07)	(0.02)	(0.01)	(0.01)
Lagged efficiency measure	−0.14***	−0.83***	−0.71***	−0.04***
	(0.01)	(0.01)	(0.01)	(0.01)
R^2	0.10	0.44	0.36	0.16

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)	HM
HF – Mutual funds	−1.49***	−0.44***	−0.09**	−0.26***
	[16.52]	[7.77]	[4.63]	[17.37]
HF – Banks and insurance	−1.46***	−0.50***	−0.05	−0.27***
	[17.22]	[8.64]	[1.29]	[25.49]
HF – Others	−1.75***	−0.57***	−0.11**	−0.29***
	[21.64]	[12.02]	[6.54]	[25.22]

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)*), 30-minute quote midpoint return autocorrelations (*AC(30)*), and the Hou and Moskowitz (*HM*) measure 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.

(2009), we also estimate the model in levels. As shown in column (1) of Table 11, the aggregate institutional holdings are negatively related to PEV, similar to the findings of Boehmer and Kelly (2009). In addition, columns (2)–(4) show that the holdings of most types of institutional investors, including mutual funds, banks, and hedge funds, are associated with greater price efficiency. However, hedge fund holdings are associated with lower mispricing than those of other institutional investors, regardless of whether the regressions are estimated in levels or in changes (compare Panel B of Table 11 with Panel B of Table 6). We note that this result is largely driven by recent changes in hedge fund holdings. In untabulated regressions, we decompose hedge fund holdings into the previous period's holdings and the recent change in holdings following Gompers and Metrick (2001), and find

Table 11
Cross-sectional regressions of PEV on the level of institutional holdings

Panel A. Parameter estimates

	(1)	(2)	(3)	(4)
Intercept	0.25***	0.59***	0.58***	0.89***
	(0.05)	(0.07)	(0.07)	(0.08)
Aggregate inst. hldg.	−0.15***			
	(0.04)			
Hedge fund hldg.		−1.83***	−2.07***	−1.72***
		(0.37)	(0.37)	(0.36)
Mutual fund hldg.		−0.17***	−0.18***	0.05
		(0.05)	(0.04)	(0.03)
Bank and insurance hldg.		−0.23***	−0.28***	0.09
		(0.07)	(0.07)	(0.07)
Others hldg.		−0.02	−0.05	0.02
		(0.02)	(0.04)	(0.04)
Log of no. of owners		−0.26***	−0.25***	−0.42***
		(0.02)	(0.02)	(0.02)
Lagged PEV	0.95***	0.90***	0.89***	0.75***
	(0.01)	(0.01)	(0.01)	(0.01)
Short interest ratio	–	–	0.37***	0.23**
	–	–	(0.13)	(0.10)
Log of total assets	–	–	0.01	0.02
	–	–	(0.03)	(0.02)
Book-to-market	–	–	0.08***	0.03***
	–	–	(0.02)	(0.01)
Leverage	–	–	−0.03	−0.07
	–	–	(0.02)	(0.05)
Standard deviation	–	–	–	1.65***
	–	–	–	(0.18)
Turnover	–	–	–	−0.05***
	–	–	–	(0.01)
Effective spread	–	–	–	1.05***
	–	–	–	(0.12)
R^2	0.83	0.89	0.90	0.92

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

	(2)	(3)	(4)
HF – Mutual funds	−1.66***	−1.89***	−1.77***
	[20.28]	[26.15]	[23.84]
HF – Banks and insurance	−1.60***	−1.79***	−1.81***
	[18.49]	[22.78]	[24.53]
HF – Others	−1.81***	−2.02***	−1.74***
	[24.12]	[29.85]	[28.05]

This table shows estimates from cross-sectional regressions of pricing error variance (PEV) on the lagged institutional holdings and several control variables. The regressions are estimated in levels. 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.

that the relation between hedge fund holdings and changes in price efficiency is largely due to the recent change in holdings. Ownership in the previous period is not significantly related to future efficiency gains, indicating that our model based on changes in institutional ownership is well specified.

Table 12
Regressions of changes in institutional holdings on past changes in efficiency

Explanatory variable	Dependent 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)
Δ HM [t-1]	−0.01	−0.04	0.01	−0.03
	(0.02)	(0.07)	(0.03)	(0.05)

This table reports the slope coefficients 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 and standard errors are multiplied by 100 for ease of exposition. The superscripts * and ** indicate statistical significance at the 10% and 5% level, respectively.

Given that 13F filings are typically filed and made public about 45 days after the report date, other investors may learn the hedge fund position information only in the second or third month after the filing (e.g., Aragon, Hertzel, and Shi, 2013). To see if other investors can benefit from mimicking hedge fund trades and make the market more efficient by doing so, we also test whether the results in Table 6 are sensitive to measuring efficiency at different time points. Instead of measuring price efficiency during the month that immediately follows the quarter-end, we average the monthly measures of efficiency over the entire quarter. Alternatively, we also measure efficiency during the last month in each quarter. The coefficient estimates for both tests are consistent with those reported in Table 6, although less significant across all types of institutions. Hence, we conclude from these tests that the efficiency improvements largely occur before the holdings are made public and therefore do not likely reflect the actions of "copycat" investors mimicking hedge fund strategies. However, the quarterly frequency of the holdings may limit our ability to reliably identify the effect of "copycat" trades.

Next, we examine whether the effects of hedge fund ownership on PEV differ for stocks traded on NYSE or NASDAQ, and across different size deciles. While the effect of hedge funds is greater among small stocks and stocks listed on NASDAQ, the results are robust to excluding the smallest market capitalization decile from the analysis. These tests confirm that the results are not driven by a subset of outliers or stocks where efficiency is difficult to measure due to a lack of liquidity. We omit the subsample tests to conserve space, but they are available on request.

Finally, we test whether the results could be driven by reverse causality. Recall that the results in Section 4.1 show that hedge funds have a preference for less efficiently priced stocks, making it unlikely that the relation between changes in hedge fund holdings and the stocks' greater price efficiency is due to reverse causality. As a further test, 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 12. We find 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. Thus, the relation between hedge fund holdings and efficiency is unlikely to be driven by reverse causality.

5. Conclusion

Hedge funds have been portrayed both as rational arbitrageurs who improve market efficiency by exploiting mispricing and as leveraged speculators whose active trading strategies can destabilize markets. To distinguish between these two hypotheses, we analyze the relation between 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, hedge funds prefer stocks that are relatively inefficiently priced, and these stocks experience significant improvements in price efficiency after hedge funds increase their ownership. These findings are based on high and lower frequency measures of price efficiency such as pricing error variance, return autocorrelations, variance ratios, and a price delay measure. The effects are stronger among stocks held by hedge funds with high turnover, small size, and superior stock picking skills. 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 significantly 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, in particular the crisis that followed the bankruptcy of Lehman Brothers in September 2008 and the so-called Quant Meltdown in August 2007, 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 the crisis, in particular if the hedge funds use leverage in combination with lenient redemption policies or used Lehman Brothers as a prime broker. 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. 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. These results strongly suggest that hedge fund trading improves market efficiency by incorporating information into stock prices. We conclude that hedge fund ownership positively contributes to the informational efficiency of stock prices but its effect can become negative during liquidity crises. Our findings provide new insights into the effects of hedge funds on the quality and functioning of financial markets.

Appendix: 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:[20]

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

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; 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 (truncated at five lags) can be written as:

$$r_t = \sum_{j=0}^{5} a_j^* v_{1,t-j} + \sum_{j=0}^{5} b_j^* v_{2,t-j}. \quad \text{A.2}$$

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:

$$s_t = \sum_{j=0}^{5} \alpha_j v_{1,t-j} + \sum_{j=0}^{5} \beta_j v_{2,t-j}. \quad \text{A.3}$$

[20] If we use data over earlier periods, our estimates of PEV closely match those reported in Hasbrouck (1993) and Boehmer and Kelly (2009).

where $\alpha_j = \sum_{k=j+1}^{5} a_k^*$, and $\beta_j = \sum_{k=j+1}^{5} b_k^*$. The magnitude of the pricing error is measured by its standard deviation (σ_S):

$$\sigma_S = \sqrt{\sum_{j=1}^{5} [\alpha_j \;\; \beta_j] Cov(v) [\alpha_j \;\; \beta_j]'} \; . \qquad \text{A.4}$$

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 the difference in log transaction prices, and use this ratio expressed in percent as the standardized PEV.

References

Agarwal, V., W. Jiang, Y. Tang, and B. Yang. 2013. Uncovering hedge fund skills from the portfolio holdings they hide. *Journal of Finance* 68:739–783.

Agarwal, V., N. D. Daniel, and N. Y. Naik. 2009. Role of managerial incentives and discretion in hedge fund performance. *Journal of Finance* 64:2221–2256.

Akbas, F., W. Armstrong, S. Sorescu, and A. Subrahmanyam. 2015. Smart money, dumb money, and capital market anomalies. *Journal of Financial Economics* 118:355–382.

Ang, A., S. Gorovyy, and G. B. Inwegen. 2011. Hedge fund leverage. *Journal of Financial Economics* 102:102–126.

Aragon, G. O., M. Hertzel, and Z. Shi. 2013. Why do hedge funds avoid disclosure? Evidence from confidential 13F filings. *Journal of Financial and Quantitative Analysis* 48, 1499–1518.

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

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

Beveridge, S., and C. 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.

Billio, M., M. Getmansky, A. W. Lo, and L. Pelizzon. 2012. Econometric measures of connectedness and systemic risk in the finance and insurance sectors. *Journal of Financial Economics* 104:535–559.

Boehmer, E., Z. R. Huszar, and B. D. Jordan. 2010. The good news in short interest. *Journal of Financial Economics* 96:80–97.

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

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

Boyson, N. M., C. W. Stahel, and R. M. Stulz. 2010. Hedge fund contagion and liquidity shocks. *Journal of Finance* 65:1789–1816.

Brav, A., W. Jiang, F. Partnoy, and R. Thomas. 2008. Hedge fund activism, corporate governance, and firm performance. *Journal of Finance* 63:1729–1775.

Brown, S., W. Goetzmann, B. Liang, and C. Schwarz. 2012. Trust and delegation. *Journal of Financial Economics* 103:221–234.

Brown, S., W. Goetzmann, and J. Park. 2010. Hedge funds and the Asian currency crisis. *Journal of Portfolio Management* 26:95–101.

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

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

Cao, C., Y. Chen, B. Liang, and A. W. Lo. 2013. Can hedge funds time market liquidity? *Journal of Financial Economics* 109:493–516.

Cao, C., Y. Chen, W. Goetzmann, and B. Liang. 2016. *The role of hedge funds in the security price formation process. Working Paper*, Yale University.

Cao, C., B. A. Goldie, B. Liang, and L. Petrasek. 2016. What is the nature of hedge fund manager skills? Evidence from the risk-arbitrage strategy. *Journal of Financial and Quantitative Analysis* 51:929–957.

Cao, C., and L. Petrasek. 2014a. Liquidity risk and institutional ownership. *Journal of Financial Markets* 21:76–97.

———. 2014b. Liquidity risk in stock returns: An event study perspective. *Journal of Banking and Finance* 45:72–83.

Carhart, M. 1997. On persistence in mutual fund performance. *Journal of Finance* 52, 57–82.

Chen, H., N. Jegadeesh, and R. 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, T., R. Roll, and A. Subrahmanyam. 2005. Evidence on the speed of convergence to market efficiency. *Journal of Financial Economics* 76:271–292.

Daniel, K., M. Grinblatt, S. Titman, and R. Wermers. 1997. Measuring mutual fund performance with characteristics–based benchmarks. *Journal of Finance* 52:1035–1058.

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

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

Dow, J., and R. Rahi. 2003. Informed trading, investment, and welfare. *Journal of Business* 76:439–454.

Edelen, R. M., O. S. Ince, and G. S. Kadlec. 2016. Institutional investors and stock return anomalies. *Journal Financial Economics* 119:472–488.

Fama, E. F. 1970. Efficient capital markets: A review of theory and empirical work. *Journal of Finance* 25:383–417.

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

Ferson, W., and H. Mo. 2016. Performance measurement with selectivity, market and volatility timing. *Journal Financial Economics* 121:93–110.

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

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

Griffin, J. M., J. H. Harris, T. Shu, and S. Topaloglu. 2011. Who drove and bust the tech bubble? *Journal of Finance* 66:1251–1290.

Grinblatt, M., and S. Titman. 1993. Performance measurement without benchmarks: An examination of mutual fund returns. *Journal of Business* 66:47–68.

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

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

Hou, K., and T. J. Moskowitz. 2005. Market frictions, price delay, and the cross-section of expected returns. *Review of Financial Studies* 18:982–1020.

Kang, N., P. Kondor, and R. Sadka. 2014. Do hedge funds reduce idiosyncratic risk? *Journal of Financial and Quantitative Analysis* 49:843–877.

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

Kokkonen, J., and M. Suominen. 2015. Hedge funds and stock market efficiency. *Management Science* 61:2890–2904.

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

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

Lo, A. W. 2008. *Hedge Funds: An Analytic Perspective*. Princeton, NJ: Princeton University Press.

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

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

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

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

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

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

Sias, R., L. T. Starks, and S. Titman. 2006. Changes in institutional ownership and stock returns: Assessment and methodology. *Journal of Business* 79:2869–2910.

Sias, R., H. J. Turtle, and B. Zykaj. 2016. Hedge fund crowds and mispricing. *Management Science* 62:764–784.

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

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

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

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