Hedge Fund Leverage*

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Abstract

We investigate the leverage of hedge funds in the time series and cross section. Hedge fund leverage is counter-cyclical to the leverage of listed financial intermediaries and decreases prior to the start of the financial crisis in mid-2007. Hedge fund leverage is lowest in early 2009 when the market leverage of investment banks is highest. Changes in hedge fund leverage tend to be more predictable by economy-wide factors than by fund-specific characteristics. In particular, decreases in funding costs and increases in market values both forecast increases in hedge fund leverage. Decreases in fund return volatilities predict future increases in leverage.

1 Introduction

The events of the financial crisis over 2007-2009 have made clear the importance of leverage of financial intermediaries to both asset prices and the overall economy. The observed "deleveraging" of many listed financial institutions during this period has been the focus of many regulators and the subject of much research.[1] The role of hedge funds has played a prominent role in these debates for several reasons. First, although in the recent financial turbulence no single hedge fund has caused a crisis, the issue of systemic risks inherent in hedge funds has been lurking since the failure of the hedge fund LTCM in 1998.[2] Second, within the asset management industry, the hedge fund sector makes the most use of leverage. In fact, the relatively high and sophisticated use of leverage is a defining characteristic of the hedge fund industry. Third, hedge funds are large counterparties to the institutions directly overseen by regulatory authorities, especially commercial banks, investment banks, and other financial institutions which have received large infusions of capital from governments.

However, while we observe the leverage of listed financial intermediaries through periodic accounting statements and reports to regulatory authorities, little is known about hedge fund leverage despite the proposed regulations of hedge funds in the U.S. and Europe. This is because hedge funds are by their nature secretive, opaque, and have little regulatory oversight. Leverage plays a central role in hedge fund management. Many hedge funds rely on leverage to enhance returns on assets which on an unlevered basis would not be sufficiently high to attract funding. Leverage amplifies or dampens market risk and allows funds to obtain notional exposure at levels greater than their capital base. Leverage is often employed by hedge funds to target a level of return volatility desired by investors. Hedge funds use leverage to take advantage of mispricing opportunities by simultaneously buying assets which are perceived to be underpriced and shorting assets which are perceived to be overpriced. Hedge funds also dynamically manipulate leverage to respond to changing investment opportunity sets.

We are the first paper, to our knowledge, to formally investigate hedge fund leverage using

[1] See, for example, Adrian and Shin (2009), Brunnermeier (2009), Brunnermeier and Pedersen (2009), and He, Khang, and Krishnamurthy (2010), among many others.

[2] Systemic risks of hedge funds are discussed by the President's Working Group on Financial Markets (1999), Chan et al. (2007), Kambhu, Schuermann, and Stiroh (2007), Financial Stability Forum (2007), and Banque de France (2007).

actual leverage ratios with a unique dataset from a fund-of-hedge funds. We track hedge fund leverage in time series from December 2004 to October 2009, a period which includes the worst periods of the financial crisis from 2008 to early 2009. We characterize the cross section of leverage: we examine the dispersion of leverage across funds and investigate the macro and fund-specific determinants of future leverage changes. We compare the leverage and exposure of hedge funds with the leverage and total assets of listed financial companies. As well as characterizing leverage at the aggregate level, we investigate the leverage of hedge fund sectors.

The prior work on hedge fund leverage are only estimates (see, e.g., Banque de France, 2007; Lo, 2008) or rely only on static leverage ratios reported by hedge funds to the main databases. For example, leverage at a point in time is used by Schneeweis et al. (2004) to investigate the relation between hedge fund leverage and returns. Indirect estimates of hedge fund leverage are computed by McGuire and Tsatsaronis (2008) using factor regressions with time-varying betas. Even without considering the sampling error in computing time-varying factor loadings, this approach requires that the complete set of factors be correctly specified, otherwise the implied leverage estimates suffer from omitted variable bias. Regressions may also not adequately capture abrupt changes in leverage. Other work by Brunnermeier and Pedersen (2009), Gorton and Metrick (2009), Adrian and Shin (2010), and others, cite margin requirements, or haircuts, as supporting evidence of time-varying leverage taken by proprietary trading desks at investment banks and hedge funds. These margin requirements give maximum implied leverage, not the actual leverage that traders are using. In contrast, we analyze actual leverage ratios of hedge funds.

Our work is related to several large literatures, some of which have risen to new prominence with the financial crisis. First, our work is related to optimal leverage management by hedge funds. Duffie, Wang and Wang (2008) and Dai and Sundaresan (2010) derive theoretical models of optimal leverage in the presence of management fees, insolvency losses, and funding costs and restrictions at the fund level. At the finance sector level, Acharya and Viswanathan (2008) study optimal leverage in the presence of moral hazard and liquidity effects showing that due to deleveraging, bad shocks that happen in good times are more severe. A number of authors have built equilibrium models where leverage affects the entire economy. In Fostel and Geanakoplos (1998), economy-wide equilibrium leverage rises in times of low volatility and falls in periods where uncertainty is high and agents have very disperse beliefs. Leverage amplifies liquidity losses and leads to over-valued assets during normal times. Stein (2009) shows that leverage may be chosen optimally by individual hedge funds, but this may create a fire-sale externality causing systemic risk by hedge funds simultaneously unwinding positions and reducing leverage. There are also many models where the funding available to financial intermediaries, and hence leverage, affects asset prices. In many of these models, deleveraging cycles are a key part of the propagating mechanism of shocks.[3] Finally, a large literature in corporate finance examines how companies determine optimal leverage. Recently, Welch (2004) studies the determinants of firm debt ratios and finds that approximately two-thirds of variation in corporate leverage ratios is due to net issuing activity.

The remainder of the paper is organized as follows. We begin in Section 2 by defining and describing several features of hedge fund leverage. Section 3 describes our data. Section 4 outlines the estimation methodology which allows us to take account of missing values. Section 5 presents the empirical results. Finally, Section 6 concludes.

2 The Mechanics of Hedge Fund Leverage

2.1 Gross, Net, and Long-Only Leverage

A hedge fund holds risky assets in long and short positions together with cash. Leverage measures the extent of the relative size of the long and short positions in risky assets relative to the size of the portfolio. Cash can be held in both a long position or a short position, where the former represents short-term lending and the latter represents short-term borrowing. The assets under management (AUM) of the fund is cash plus the difference between the fund's long and short positions and is the value of the claim all investors have on the fund. The net asset value per share (NAV) is the value of the fund per share and is equal to AUM divided by the number of shares. We use the following three definitions of leverage, which are also widely used in industry:

[3] See, for example, Gromb and Vayanos (2002), He and Krishnamurthy (2009), Brunnermeier and Pedersen (2009), and Adrian and Shin (2010).

Gross Leverage is the sum of long and short exposure per share divided by NAV. This definition implicitly treats both the long and short positions as separate sources of profits in their own right, as would be the case for many long-short equity funds. This leverage measure overstates risk if the short position is used for hedging and does not constitute a separate active bet. If the risk of the short position by itself is small, or the short position is usually taken together with a long position, a more appropriate definition of leverage may be:

Net Leverage is the difference between long and short exposure per share expressed as a proportion of NAV. The net leverage measure captures only the long positions representing active positions which are not perfectly offset by short hedges, assuming the short positions represent little risk by themselves. Finally, we consider,

Long-Only Leverage or *Long Leverage* is defined as the long positions per share divided by NAV. Naturally, by ignoring the short positions, long-only leverage could result in a large under-estimate of leverage, but we examine this conservative measure because the reporting requirements of hedge fund positions by the SEC involve only long positions.[4] We also investigate if long leverage behaves differently from gross or net leverage, or put another way, if hedge funds actively manage their long and short leverage positions differently.

Only a fund 100% invested in cash has a leverage of zero for all three leverage definitions. Furthermore, for a fund employing only levered long positions, all three leverage measure coincide. Thus, active short positions induce differences between gross, net, and long-only leverage. Appendix A illustrates these definitions of leverage for various hedge fund portfolios.

2.2 How do Hedge Funds Obtain Leverage?

Hedge funds obtain leverage through a variety of means, which depend on the type of securities traded by the hedge fund, the creditworthiness of the fund, and the exchange, if any, on which

[4] Regulation 13-F filings are required by any institutional investor managing more than $100 million. Using these filings, Brunnermeier and Nagel (2004) examine long-only hedge fund positions in technology stocks during the late 1990s bull market.

the securities are traded. Often leverage is provided by a hedge fund's prime broker, but not all hedge funds use prime brokers.[5] By far the vast majority of leverage is obtained through short-term funding as there are very few hedge funds able to directly issue long-term debt or secure long-term borrowing.

In the U.S., regulations govern the maximum leverage permitted in many exchange-traded markets. The Federal Reserve Board's Regulation T (Reg T) allows investors to borrow up to a maximum 50% of a position on margin (which leads to a maximum level of exposure equal $1/0.5 = 2$). For a short position, Reg T requires that short sale accounts hold collateral of 50% of the value of the short implying a maximum short exposure of two. By establishing offshore investment vehicles, hedge funds can obtain "enhanced leverage" higher than levels of than allowable by Reg T. Prime brokers have established facilities overseas in less restrictive jurisdictions in order to provide this service. Another way to obtain higher leverage than allowed by Reg T is "portfolio margining" which is another service provided by prime brokers. Portfolio margining was approved by the SEC in 2005 and allows margins to be calculated on a portfolio basis, rather than on a security by security basis.[6]

Table 1 reports typical margin requirements ("haircuts") required by prime brokers or other counterparties. The last column of the Table 1 lists the typical levels of leverage able to be obtained in each security market, that are the inverse of the margin requirements. This data is obtained at March 2010 by collating information from prime brokers and derivatives exchanges.[7] Note that some financial instruments, such as derivatives and options, have embedded leverage in addition to the leverage available from external financing. The highest leverage is available in Treasury, foreign exchange, and derivatives security markets such as interest rate and foreign exchange swaps. These swap transactions are over the counter and permit much higher levels of leverage than Reg T. These securities enable investors to have large notional exposure with little or no initial investment or collateral. Similarly, implied leverage is high in futures markets

[5] In addition to providing financing for leverage, prime brokers provide hedge fund clients with risk management services, execution, custody, daily account statements, and short sale inventory for stock borrowing. In some cases, prime brokers provide office space, computing and trading infrastructure, and may even contribute capital.

[6] Portfolio margining only applies to "hardwired" relations, such as calls and puts on a stock, and the underlying stock itself, rather than to any statistical correlations between different assets.

[7] Brunnermeier and Pedersen (2009) and Gorton and Metrick (2009) show that margin requirements changed substantially over the financial crisis.

because the margin requirements there are much lower than in the equity markets.

Based on the dissimilar margin requirements of different securities reported in Table 1, it is not surprising that hedge fund leverage is heterogeneous and depends on the type of investment strategy employed by the fund. Our results below show that funds engaged in relative value strategies, which trade primarily fixed income, swaps, and other derivatives, have the highest average gross leverage of 4.8 through the sample. Some relative value funds in our sample have gross leverage greater than 30. Credit funds which primarily hold investment grade and high yield corporate bonds and credit derivatives have an average gross leverage of 2.4 in our sample. Hedge funds in the equity and event driven strategies mainly invest in equity and distressed corporate debt and hence have lower leverage. In particular, equity and event driven funds have average gross leverage of 1.6 and 1.3, respectively over our sample.

The cost of leverage to hedge funds depends on the method used to obtain leverage. Prime brokers typically charge a spread over LIBOR to hedge fund clients who are borrowing to fund their long positions and brokers pay a spread below LIBOR for cash deposited by clients as collateral for short positions. These spreads are higher for less credit worthy funds and are also higher when securities being financed have high credit risk or are more volatile. The cost of leverage through prime brokers reflects the costs of margin in traded derivatives markets. We include instruments capturing funding costs like LIBOR and interest rate spreads in our analysis.

In many cases, there are maximum leverage constraints imposed by the providers of leverage on hedge funds. Hedge fund managers make a decision on optimal leverage as a function of the type of the investment strategy, the perceived risk-return trade-off of the underling trades, and the cost of obtaining leverage, all subject to exogenously imposed leverage limits. Financing risk is another consideration as funding provided by prime brokers can be subject to sudden change. In contrast, leverage obtained through derivatives generally have lower exposure to funding risk. Prime brokers have the ability to pull financing in many circumstances, for example, when performance or NAV triggers are breached. Dai and Sundaresan (2010) show that this structure effectively leaves the hedge funds short an option vis-à-vis their prime broker. Adding further risk to this arrangement is the fact that the hedge fund is also short an option vis-à-vis another significant financing source, their client base, which also has the ability to pull financing following terms stipulated by the offering memorandum.[8] We do not consider the implicit leverage in these funding options in our analysis as we are unable to obtain data on hedge fund prime broker agreements or the full set of investment memoranda of hedge fund clients; our analysis applies only to the leverage reported by hedge funds in their active strategies.[9]

2.3 Reported Hedge Fund Leverage

An important issue with hedge fund leverage is which securities are included in the firm-wide leverage calculation and how the contribution of each security to portfolio leverage is calculated. The most primitive form of leverage calculation is unadjusted balance sheet leverage, which is simply the value of investment assets, not including notional exposure in derivatives, divided by equity capital. Since derivatives exposure for hedge funds can be large, this understates, in many cases dramatically, economic risk exposure.

To remedy this shortcoming, leverage is often adjusted for derivative exposure by taking delta-adjusted notional values of derivative contracts.[10] For example, in order to account for the different volatility and beta exposures of underlying investments, hedge funds often beta-adjust the exposures of (cash) equities by upward adjusting leverage for high-beta stock holdings. Likewise, (cash) bond exposures are often adjusted to account for the different exposures to interest rate factors. In particular, the contribution of bond investments to the leverage calculation is often scaled up or down by calculating a 10-year equivalent bond position. Thus, an investment of $100 in a bond with twice the duration of a 10-year bond would have a position of $200 in the leverage calculation. The issues of accounting for leverage for swaps and futures affect fixed income hedge funds the most and long-short equity hedge funds the least. For this reason we break down leverage statistics by hedge fund sectors.

[8] In many cases, hedge funds have the ability to restrict outflows by invoking gates even after lockup periods have expired (see, for example, Ang and Bollen, 2010).

[9] Dudley and Nimalendran (2009) estimate funding costs and funding risks for hedge funds, which are not directly observable, using historical data on margins from futures exchanges and VIX volatility. They do not consider hedge fund leverage.

[10] Many hedge funds account for the embedded leverage in derivatives positions through internal reporting systems or external, third-party risk management systems like Riskmetrics. These risk system providers compute risk statistics like deltas, left-hand tail measures of risk like Value-at-Risk, and implied leverage at both the security level and the aggregate portfolio level. Riskmetrics allows hedge funds to "pass through" their risk statistics to investors who can aggregate positions across several funds.

Funds investing primarily in futures, especially commodities, report a margin-to-equity ratio, which is the amount of cash used to fund margin divided by the nominal trading level of the fund. This measure is proportional to the percentage of available capital dedicated to funding margin requirements. It is frequently used by commodity trading advisors as a gauge of their market exposure. Other funds investing heavily in other zero-cost derivative positions like swaps also employ similar measures based on ratios of nominal, or adjusted nominal exposure, to collateral cash values to compute leverage.

Thus, an important caveat with our analysis is that leverage is not measured in a consistent fashion across hedge funds and the hedge funds in our sample use different definitions of leverage. Our data is also self-reported by hedge funds. These effects are partially captured in our analysis through fund fixed effects. Our analysis focuses on the common behavior of leverage across hedge funds rather than explaining the movements in leverage of a specific hedge fund.

3 Data

3.1 Macro Data

We capture the predictable components of hedge fund leverage by various aggregate market price variables, which we summarize in Appendix B. We graph two of these variables in Figure 1. We plot the average cost of protection from a default of major "investment banks" (Bear Stearns, Citibank, Credit Suisse, Goldman Sachs, HSBC, JP Morgan, Lehman Brothers, Merrill Lynch, and Morgan Stanley) computed using credit default swap (CDS) contracts in the solid line with the scale on the left-hand axis. This is the market-weighted cost of protection per year against default of each firm. Our selected firms are representative of broker/dealers and investment banking activity and we refer to them as investment banks even though many of them are commercial banks and some became commercial banks during the sample period.

In Figure 1 we also plot the VIX volatility index in the dotted line with the scale on the right-hand axis. The correlation between VIX and investment bank CDS protection is 0.89. Both of these series are low at the beginning of the sample and then start to increase in mid-2007, which coincides with the initial losses in subprime mortgages and other certain securitized markets. In late 2008, CDS spreads and VIX increase dramatically after the bankruptcy of

Lehman Brothers, with VIX reaching a peak of 60% at the end of October 2008 and the CDS spread reaching 3.55% per annum in September 2008. In 2009, both CDS and VIX decline after the global financial sector is stabilized.

Our other macro series are monthly returns on investment banks, monthly returns on the S&P 500, the three-month LIBOR rate, and the three-month Treasury over Eurodollar (TED) spread. The LIBOR and TED spreads are good proxies for the aggregate cost of short-term borrowing for large financial institutions. Prime brokers pass on at least the LIBOR and TED spread costs to their hedge fund clients plus a spread. Finally, we also include the term spread, which is the difference between the 10-year Treasury bond yield and the yield on three-month T-bills. This captures the slope of the yield curve, which under the Expectations Hypothesis is a forward-looking measure of future short-term interest rates and thus provides a simple way of estimating future short-term borrowing costs.

3.2 Hedge Fund Data

Our hedge fund data is obtained from a large fund-of-hedge-funds (which we refer to as the "Fund"). The original dataset from the Fund contains over 45,000 observations of 758 funds from February 1977 to December 2009. In addition to hedge fund leverage, our data includes information on the strategy employed by the hedge funds, monthly returns, NAVs, and AUMs. The hedge funds are broadly representative of the industry and contain funds managed in a variety of different styles including global macro funds, fundamental stock-picking funds, credit funds, quantitative funds, and funds investing using technical indicators. The hedge funds invest both in specific asset classes, for example, fixed income or equities, and also across global asset classes. Our data includes both U.S. and international hedge funds, but all returns, NAVs, and AUMs are in US dollars.

An important issue is whether the hedge funds in the database exhibit a selection bias. In particular, do the hedge funds selected by the Fund have better performance and leverage management than a typical hedge fund? The Fund selects managers using both a "top down" and a "bottom up" approach. The former involves selecting funds in various sector allocation bands for the Fund's different fund-of-fund portfolios. The latter involves searching for funds, or re-allocating money across existing funds, using a primarily qualitative, proprietary approach.

Leverage is a consideration in choosing funds, but it is only one of many factors among the usual suspects – Sharpe ratios and other performance criteria, due diligence considerations, network, manager quality, transparency, gates and restrictions, sector composition, investment style, etc. The Fund did not add leverage to its products and only very rarely asked hedge funds to provide a customized volatility target or to provide leverage which differed from the hedge funds' existing product offerings. There is no reason to believe that the Fund's selection procedure results in funds with leverage management practices that are significantly different to the typical hedge fund.

Our Fund database includes funds that are present in TASS, CISDM, Barclay Hedge, or other databases commonly used in research and also includes other funds which do not report to the public hedge fund databases. This mitigates the reporting bias of the TASS database (see Malkiel and Saha, 2005; Ang, Rhodes-Kropf, and Zhao, 2008; Agarwal, Fos, and Jiang, 2010). However, the composition by sector is similar to the overall sector weighting of the industry as reported by TASS and Barclay Hedge. Survival biases are mitigated by the fact that often hedge funds enter the database not when they receive funds from the Fund, but several months prior to the Fund's investment and they often exit the database several months after disinvestment. Our database also includes hedge funds which terminate due to poor performance. The aggregate performance of the Fund is similar to the performance of the main hedge fund indexes.

3.2.1 Hedge Fund Leverage

Leverage is reported by different hedge funds at various frequencies and formats, which are standardized by the Fund. Appendix C discusses some of these formats. Most reporting is at the monthly frequency, but some leverage numbers are reported quarterly or even less frequently. For those funds reporting leverage at the quarterly or at lower frequencies, the Fund is often able to obtain leverage numbers directly from the hedge fund managers at other dates through a combination of analyst site visits and calls to hedge fund managers. The data is of high quality because the funds undergo thorough due diligence by the Fund. In addition, the performance and risk reports are audited, and the Fund conducts regular, intensive monitoring of the investments made in the individual hedge funds.

3.2.2 Hedge Fund Returns, Volatilities, and Flows

We have monthly returns on all the hedge funds. These returns are actual realized returns, rather than returns reported to the publicly available databases. In addition to examining the relation between past returns and leverage, we construct volatilities from the returns. We construct monthly hedge fund volatility using the sample standard deviation of returns over the past 12 months. Figure 2 plots the volatilities of all hedge funds and different hedge fund strategies over the sample. The volatilities follow the same broad trend and are approximately the same. This is consistent with hedge funds using leverage to scale returns to similar volatility levels.

Figure 2 shows that at the beginning of the sample, hedge fund volatilities were around 3% per month and reach a low of around 2% per month in 2006. As subprime mortgages start to deteriorate in mid-2007, hedge fund return volatility starts to increase and reaches 4-5% per month by 2009. Volatility stays at this high level until the end of the sample in October 2009. This is because we use rolling 12-month sample volatilities which include the very volatile, worst periods of the financial crisis 12 months prior to October 2009.

Figure 3 compares the rolling 12-month volatilities of hedge fund returns in the data sample with the rolling 12-month volatilities of hedge fund returns in the HFR database for the December 2004 - October 2009 time period. We observe that the average volatilities of hedge funds in the data closely track the median hedge fund volatility in the HFR database. Thus, the Funds hedge funds have very similar return behavior as the typical hedge fund reported on the publicly available databases. Since hedge funds often use leverage to target particular levels of volatility, this partially alleviates concerns that the Fund's hedge funds have atypical leverage policies.

In addition to hedge fund volatility, we also use hedge fund flows as a control variable. We construct hedge fund-level flows over the past three months using the return and AUM information from the following formula:

$$Flow_t = \frac{AUM_t}{AUM_{t-3}} - (1 + R_{t-2})(1 + R_{t-1})(1 + R_t) \tag{1}$$

where $Flow_t$ is the past three-month flow in the hedge fund, AUM_t is assets under management at time t and R_t is the hedge fund return from $t - 1$ to t. The flow formula in equation (1) is used by Chevalier and Ellison (1997), Sirri and Tufano (1998), and Agarwal, Daniel, and Naik (2009), among others. We compute three-month flows as the flows over the past month tend to be very volatile. We also compute past three-month hedge fund flows for the aggregate hedge fund industry as measured by the Barclay Hedge database using equation (1).

3.3 Summary Statistics

We clean the raw data from the Fund and impose two filters. First, often investments are made by the Fund in several classes of shares of a given hedge fund. All of these share classes have almost identical returns and leverage ratios. We use the share class with the longest history or the share class representing the largest AUM. Our second filter is that we require funds to have at least two years of leverage observations. The final sample spans December 2004 to October 2009 and thus our sample includes the poor returns of quantitative funds during Summer 2007 (see Khandani and Lo, 2007) and the financial crisis of 2008 and early 2009. There are at least 63 funds in our sample at any one time. The maximum number of funds at any given month is 163 over the sample period.

Panel A of Table 2 lists the number of observations and number of hedge funds broken down by strategy. The strategies are defined by the Fund and do not exactly correspond to the sector definitions employed by TASS, Barclay Hedge, CSDIM or other hedge fund databases (which themselves employ arbitrary sector definitions). The TASS categories of fixed income arbitrage and convertible arbitrage fall under the Fund's relative value sector. In the relative value sector, hedge funds invest in both developed and emerging markets and can also invest in a variety of different asset classes. Most of the Fund's investments have been in long-short equity funds in the equity category and this is also by far the largest hedge fund sector in TASS, as reported, for example, by Chan et al. (2007). At the last month of our sample, October 2009, the proportion of equity funds reported in Barclay Hedge, not including multi-strategy, other, and sector-specific categories, is also over 40%.

After our data filters, there are a total of 208 unique hedge funds in our sample with 8,136 monthly observations. Over half (114) of the funds in our sample run long-short equity strategies. The number of funds in the areas of credit and relative value are 21 and 36, respectively. The remaining 37 funds are in the event driven strategy, which are mainly merger arbitrage and distressed debt. The number of funds reported in Panel A of Table 2 is large enough for reliable inference when averaged across strategies and across all hedge funds.[11]

In Panel B of Table 2, we report summary statistics of all the hedge fund variables observed in the sample. These statistics should be carefully interpreted because they do not sample all hedge funds at the same frequency and there are missing observations in the raw data. Panel B reports that the average gross leverage across all hedge funds is 2.13 with a volatility of 0.62. This volatility is computed using only observed data and the true volatility of leverage, after estimating the unobserved values, will be lower, as we show below. Nevertheless, it is clear that hedge fund leverage changes over time. Even without taking into account missing observations, this volatility is much lower than the volatility of leverage reported in the estimations of McGuire and Tsataronis (2008) using factor regressions. This discrepancy could possibly result from the large error in their procedure of inferring leverage from estimated factor coefficients in regressions on short samples. Individual gross hedge fund leverage is also persistent, with an average autocorrelation of 0.68 across all the hedge funds. Again because of unobserved leverage ratios, this persistence is biased downwards and we report more accurate measures of autocorrelation taking into account other predictive variables below.

Panel B of Table 2 also reports the summary statistics for the other two leverage measures. The average net leverage of hedge funds is 0.59 and average long-only leverage is 1.36. The raw volatilities of net leverage and long-only leverage are 0.28 and 0.38 respectively, which are significantly lower than the volatility of gross leverage. Thus, in our analysis, we break out gross, net, and long-only leverage separately.

The other variables reported in Panel B of Table 2 are control variables used in our analysis. The average hedge fund return is 29 basis points per month. These returns are autocorrelated, with an average autocorrelation of 0.24 across funds, which indicates that out- or underperforming manager returns are persistent, as noted by Getmansky, Lo, and Makarov (2004) and Jagannathan, Malakhov, and Novikov (2010). The returns are lower than those reported by previous literature because our sample includes the financial crisis during which many hedge funds did poorly.[12] The average 12-month rolling volatility across hedge funds is 2.65% per

[11] The sample also includes commodity trading funds and global macro funds, but we do not break out separate performance of these sectors as there are too few funds for reliable inference.

[12] See, among many others, Fung and Hsieh (1997, 2001), Brown, Goetzmann and Ibbotson (1999), and more recently Bollen and Whaley (2009).

month. The volatility is computed only when all fund returns in the previous 12 months are observed. This explains why only approximately 70% of fund volatilities are observed. Nevertheless, our volatility estimates are close to those reported in the literature by Ackermann, McEnally, and Ravenscraft (1999) and Chan et al. (2007), among others.

The last two fund-specific variables we include are past three-month hedge fund flows and log AUMs. Flows are on average positive, at 2.2% per month and exhibit a large average autocorrelation of 0.62. The average fund size over our sample is $962 million. The median fund size is $430 million. The difference between mean and median of fund size is explained by the presence of some large funds, with the largest funds having AUMs well over $10 billion in just one share class. Our sample is slightly biased upwards in terms of size compared to recent estimates such as those by Chan et al. (2007) and the Banque de France (2007). This is due to the application of filters which tend to remove smaller funds which are effectively different share classes of larger funds. Our filters also remove funds which are in their infancy. These funds are likely to have lower levels of leverage, with more onerous financing conditions, than more established funds, making the levels of our leverage ratios conservatively biased upwards.

The last column in Panel B, Table 2 lists the proportion of months across all funds where the variables are observed. While we always observe returns, the leverage variables are observed approximately 80% of the time. We do not restrict our analysis to a special subset of data where all variables are observed. Instead, our algorithm permits us to use all the available data and to infer the leverage ratios when they are missing. We now discuss our estimation methodology.

4 Methodology

4.1 Predictive Model

We specify that leverage over at month $t+1$ for fund i, $L_{i,t+1}$, is predictable at time t by both economy-wide variables, x_t, and fund-specific variables, which we collect in the vector $y_{i,t}$, in the linear regression model:[13]

$$\Delta L_{i,t+1} = c_i + \gamma \cdot x_t + \rho \cdot y_{i,t} + \varepsilon_{i,t+1}, \tag{2}$$

[13] We also investigate the forecastability of proportional leverage changes, $\Delta L_{i,t+1}/(1+L_{i,t})$, in the same regression specification of equation (2). The results are very similar to the results for leverage changes.

where $\Delta L_{i,t+1} = L_{i,t+1} - L_{i,t}$ is the change in fund i leverage from t to $t+1$, γ is the vector of predictive coefficients on economy-wide variables, ρ is the vector of coefficients on fund-specific variables, and the idiosyncratic error $\varepsilon_{i,t+1} \sim N(0, \sigma^2)$ is i.i.d. across funds and time. The set of firm-specific characteristics, $y_{i,t}$ includes lagged leverage, $L_{i,t}$, which allows us to estimate the degree of mean reversion of the leverage employed by funds. We capture fund-fixed effects in the constants c_i which differ across each fund.

We estimate the parameters $\theta = (c_i \, \gamma \, \rho \, \sigma^2)$ using a Bayesian algorithm which also permits estimates of non-observed leverage and other fund-specific variables. Appendix D contains details of this estimation. Briefly, the estimation method treats the non-reported variables as additional parameters to be inferred along with θ. As an important byproduct, the estimation supplies posterior means of leverage ratios where these are unobserved in the data. We use these estimates, combined with the observed leverage ratios, to obtain time-series estimates of aggregate hedge fund leverage and leverage for each sector. Since we use uninformative priors, the special case where both the regressors and regressands in equation (2) are all observed in data is equivalent to running standard OLS.

An advantage of our procedure is that we are able to use all observations after imposing the data filters. Using OLS would result in very few funds and observations because both the complete set of regressors and the regressand must be observed. Taking only observed leverage produces a severely biased sample as different types of funds report at quarterly or lower frequencies versus the monthly frequency. Sudden stops in leverage reporting correlate with unexpected bad performance. Linearly interpolating unobserved leverage produces estimates that are too smooth because it relies on filling in points based on the mean reversion properties of leverage alone. We show below that other variables significantly predict leverage, both in the time series and cross section.

4.2 Contemporaneous Model

The model in equation (2) is a predictive model where leverage over the next period is forecastable by macro and fund-specific variables at the beginning of the period. We consider an alternative model where leverage is determined contemporaneously with instruments:

$$L_{i,t} = c_i + \gamma \cdot x_t + \rho \cdot y_{i,t} + \epsilon_{i,t}, \tag{3}$$

where we use the same set of macro variables in x_t as in the predictive model (2), but we now assume that the fund-specific variables, $y_{i,t}$ do not include lagged leverage.

In equation (3), the potential observable determinants of leverage like VIX, interest rate spreads, hedge fund flows, etc. in x_t and $y_{i,t}$ are persistent. The unobserved determinants, which are in the error term $\epsilon_{i,t}$, are also likely to be persistent so we specify that the errors are serially correlated and follow

$$\epsilon_t = \phi_\epsilon \epsilon_{t-1} + v_t, \tag{4}$$

where $v_t \sim$ i.i.d. $N(0, \sigma^2)$. It can be shown that accounting for the persistence in the regressands in equation (3) through VAR or autoregressive specifications produces a reduced-form model of the same form as equation (2), except without a lagged leverage term. The relation between equations (2) and (3) involves the persistence of the regressands and the strength of the serial correlation, ϕ_ϵ, of the error terms. Appendix D describes the estimation of the contemporaneous system and compares it with the predictive model.

The contemporaneous model (3) can be used to test various theories on the determinants of hedge fund leverage. It is important to note, however, that equation (3) is not a structural model. Many of the fund-specific variables, and perhaps some of the macro variables, are jointly endogenously determined with hedge fund leverage. Put another way, while equation (3) can shed light on contemporaneous correlations between hedge fund leverage and various instruments, it is silent on causation. We may expect that some variables that are contemporaneously associated with hedge fund leverage in equation (3) may have the opposite sign when used as a predictor of hedge fund leverage in equation (2). Some of this may be due to the effect of the serially correlated errors in the contemporaneous specification or that the contemporaneous vs. predictive relations between certain variables and leverage are indeed different.

5 Empirical Results

5.1 Time Series of Leverage

5.1.1 Gross Leverage

We begin our analysis by presenting the time series of gross leverage of hedge funds. This is obtained using the model in equation (2) with all macro and fund-specific variables and fund-fixed effects. We graph gross hedge fund leverage for all hedge funds and the hedge fund sectors in Figure 4. We report the posterior mean of gross leverage across all hedge funds in the solid line. Gross leverage is stable at approximately 2.3 until mid-2007 where it starts to decrease from 2.6 in June 2007 to a minimum of 1.4 in March 2009. At the end of our sample, October 2009, we estimate gross leverage across hedge funds to be 1.5. Over the whole sample, average gross leverage is 2.1. As expected from the fairly smooth transitions in Figure 4, gross leverage is very persistent with an autocorrelation of 0.97.

The patterns of gross leverage for all hedge funds are broadly reflected in the dynamics of the leverage for hedge fund sectors, which are also highly persistent with correlations well above 0.95. Leverage for event driven and equity funds is lower, on average, at 1.3 and 1.6, respectively, than for all hedge funds, which have an average gross leverage of 2.1 over the sample. Both the event driven and equity sectors reach their highest peaks of gross leverage in mid-2007 and gradually decrease their leverage over the financial crisis. Event driven leverage falls below one and reaches a low of 0.8 in December 2008 before rebounding. Credit funds steadily increase their gross leverage from 1.5 at the beginning of 2005 to reach a peak of 3.9 at June 2007. This decreases to 1.1 at the end of the sample.

Figure 4 shows that the most pronounced fall in leverage is seen in the relative value sector: relative value gross leverage reaches an early peak of 6.8 in April 2006 and starts to cut back in early 2006. This is well before the beginning of the deterioration in subprime mortgages in 2007. In December 2007, gross leverage in relative value funds falls to 4.5 and decreases slightly until a sharp increase over April to June 2008 to reach a local high of 5.8 in June 2008. These periods coincide with increasing turbulence in financial markets after the purchase of Bear Stearns by JP Morgan Chase in March 2008 and the illiquidity of many securitized asset markets.[14] The increasing leverage in early 2008 in relative value is not due to any one fund; several large funds in the database exhibit this behavior and, in general, the leverage of all relative value funds over the financial crisis is volatile. From June 2008 gross leverage of the relative value sector decreases from 5.8 to 2.3 at October 2009. Over the whole sample, relative value gross leverage is 4.8.

5.1.2 Dispersion of Gross Leverage

While Figure 4 shows the average hedge fund leverage, an open question is how the cross section of leverage changes over time. We address this in Figure 5 which plots the median and the cross-sectional interquartile range (25th and 75th percentiles) of gross leverage. The cross-sectional distribution of all leverage measures does change, but is fairly stable across the sample. Since there are some funds with very large leverage in our sample, the median falls closer to the 25th percentile than to the 75th percentile for all the leverage ratios. During 2005 to early 2007, the interquartile range for gross hedge fund leverage stays in the range 1.0 to 1.3. During mid-2007, the interquartile cross-sectional dispersion increases to 1.6 in May 2007 and then falls together with the overall decrease in leverage during this period. Interestingly, the largest decline in leverage in 2008 during the financial crisis is not associated with any significant change in the cross-section of hedge fund leverage. In summary, although hedge fund leverage is heterogeneous, the cross-sectional pattern of hedge fund leverage is fairly stable and in particular, does not significantly change in 2008 when the overall level of leverage is declining.

5.1.3 Gross vs. Net and Long-Only Leverage

In Figure 6 we plot gross, net, and long-only leverage across all hedge funds (top panel) and for hedge fund sectors (bottom four panels). The lines for gross leverage are the same as Figure 4

[14] Relative value strategies (e.g. capital structure arbitrage and convertible bond arbitrage) tend to be more sensitive to the relative relation between securities and asset classes than credit, equity, and event driven strategies, which tend to be based more on single security fundamentals. When markets showed signs of normalizing after the Bear Stearns takeover in March 2008, many relative value strategies were quick to reapply leverage to take advantage of the stabilized and converging valuations. This period of improved market conditions was brief as new financial sector shocks occurred during the Summer of 2008, at which time relative value managers quickly brought leverage down.

and are drawn so we can compare net and long-only leverage. Figure 6 shows that the three leverage measures, for all hedge funds and within the hedge fund sectors, are highly correlated and have the same broad trends. Table 3 reports correlations of the gross, net, and long-only leverage and they are all high. In particular, gross, net, and long-only leverage all have pairwise correlations above 0.92 in Panel A.

Panel B of Table 3 reports the correlations of gross, net, and long leverage for the hedge fund sectors. If there are no independent active short bets, then the correlations of all leverage measures should be one. Thus, we can infer the extent of the separate management of long and short positions by examining the correlations between gross and net leverage. The correlation of net and gross leverage is lowest for equity hedge funds, at 0.49, and above 0.80 for the other hedge fund sectors. This is consistent with funds in the equity sector most actively separately managing their long and short bets. In contrast, the highest correlation between net and gross leverage is 0.88 for relative value funds, which indicates these funds are most likely to take positions as long-short pairs.

One difference between the leverage measures in Figure 6 is that the net and long-only leverage ratios are smoother than gross leverage. For all hedge funds the standard deviation of gross leverage is 0.36, whereas the standard deviations for net and long leverage are 0.14 and 0.25, respectively. Thus, hedge funds manage the leverage associated with active long and short positions in different ways. This pattern is also repeated in each of the hedge fund sectors. The largest difference in the volatility of gross leverage compared to net leverage is for relative value, where gross and net leverage standard deviations are 1.22 and 0.20, respectively. The mean of net leverage for relative value is also much lower, at 0.82, than the average level of gross leverage at 4.84. The low volatility of net leverage for relative value funds is consistent with these funds maintaining balanced long-short positions where a large number of their active bets consist of taking advantage of relative pricing differentials between assets. The stable and low net leverage for relative value funds may also imply that focusing on gross leverage overstates the market risk of this hedge fund sector.

An interesting episode for equity hedge funds is the temporary ban on shorting financial stocks which was imposed in September 2008 and repealed one month later (see Boehmer, Jones, and Zhang, 2009, for details). Equity hedge fund leverage was already trending downwards prior to this period beginning in mid-2007 and there is no noticeable additional effect in September or October 2008 for gross leverage or long-only leverage. However, Figure 6 shows there is a small downward dip in net leverage during these months with net leverage being 0.48, 0.44, and 0.50 during the months of July, September, and October 2008, respectively. Thus, this event seems to affect the short leverage positions of equity funds, but the overall effect is small. This may be because the ban affected only the financial sector or because these hedge funds were able to take offsetting trades in derivatives markets or other non-financial firms to maintain their short positions.

Finally, we observe a high level of covariation for net and long-only leverage in Figure 6 across all hedge funds and within sectors. This is similar to the high degree of comovement of gross leverage across sectors in Figure 4. We report correlations for all hedge funds and across sectors for each leverage measure in Table 4. These cross correlations are high indicating that each leverage measure generally rises and falls in tandem for each hedge fund sector. In particular, Panel A shows that although the relative value sector contains the smallest number of funds, the correlation of gross leverage of relative value with all hedge funds is 0.93. The lowest correlation is between relative value and event driven, at 0.65. Put another way, looking at gross leverage across all hedge funds is a good summary measure for what is happening to gross leverage in the various hedge fund sectors. Panels B and C also show that this is true for net and long-only leverage. Thus, sector-level variation in hedge fund leverage is similar to the aggregate-level behavior of leverage across all hedge funds.

5.2 Macro Predictors of Hedge Fund Leverage

In this section, we discuss the ability of various macro and fund-specific variables to predict hedge fund leverage. We first report estimates of the predictive model in equation (2) taking only economy-wide variables and report the results in Table 5. We consider gross leverage in Panel A, net leverage in Panel B, and long-only leverage in Panel C. In all regressions we include lagged leverage as an independent variable. Regressions (1)-(8) add each macro variable one at a time together with lagged leverage, while all variables jointly enter regression (9). We use fund-level fixed effects in all regressions. In each panel, the coefficients on lagged leverage are negative with very high posterior t-statistics. The lagged leverage coefficients range from -0.20

to -0.31 indicating that hedge fund leverage is strongly mean-reverting.

Panel A, which reports results for gross leverage, shows that all the macro variables, with the exception of aggregate hedge fund flows, significantly predict changes in hedge fund leverage when used in conjunction with past leverage. The largest coefficient in magnitude is on investment bank CDS protection, where for a 1% increase in CDS spreads, next-month hedge fund leverage shrinks by 11.5%, on average. As investment banks perform well (regression (2)) or the S&P 500 posts higher returns (regression (3)), hedge fund leverage tends to increase next month. We observe that when volatility increases, as measured by VIX (regression (4)), or assets become riskier, as measured by the TED spread (regression (6)), hedge fund leverage tends to decrease over the next month. This is consistent with hedge funds targeting a specific risk profile of their returns, where an increase in the riskiness of the assets leads to a reduction in their exposure. In particular, a 1% movement in VIX predicts that gross leverage declines by 0.9% over the next month and a 1% increase in the TED spread predicts gross leverage will fall over the next month by 15.2%.

In regression (5), the sign on LIBOR is unexpectedly positive. We might expect increases in funding rates, of which LIBOR should be a large component, to decrease future leverage. Instead, the coefficient on LIBOR is positive at 4.35. This is surprising given that Figure 4 shows that hedge fund leverage decreases before and during the financial crisis. However, in the joint regression (9), the coefficient on LIBOR flips sign and is now negative at -6.66. Thus, controlling for other variables, which are significantly correlated especially over the 2007-9 period, produces the expected negative relation between LIBOR and future leverage changes. In fact, LIBOR, the TED spread, CDS spreads, and VIX are very highly correlated, all around 90%, and capture common effects associated with the financial crisis over the sample period. Thus, it is not surprising that the coefficient on VIX also becomes insignificant in the joint regression (9). In contrast, the term spread coefficients are consistently negative as expected, which implies that higher expected funding costs reduce leverage next period.

In regression (9) where we take all macro variables together, the predictors of hedge fund leverage which have posterior t-statistics greater than two in absolute value are investment bank CDS spreads, the lagged S&P 500 return, LIBOR, and the term spread. Increases in current funding costs, as measured by CDS spreads and LIBOR predict decreases in leverage, as do increases in future expected funding costs, as measured by the term spread.

In Panels B and C of Table 5, we report estimates of the same regressions for net and long-only leverage. In Panel B, all the coefficients on the macro variables are significant in the bivariate regressions (1)-(8), with the same signs as Panel A for gross leverage but with smaller magnitudes. However, there are no significant macro predictors of net leverage in the joint regression (9). Thus, overall net leverage is mostly determined only by its lagged value. Said differently, the only significant distinguishing feature of net leverage predictability is that it is highly mean reverting. In Panel C, long-only leverage is significantly predicted by each individual macro variable in regressions (1)-(8) with the same signs as gross leverage in Panel A. The last column in Panel C for regression (9) reports that increases in the cost of investment bank CDS protection and the term spread significantly lower future long leverage. This indicates that most of the predictability in gross leverage by macro determinants in Panel A is coming from the predictability of long-only leverage by macro variables.

5.3 Fund-Specific Predictors of Hedge Fund Leverage

In Table 6 we examine the ability of fund-specific variables to predict hedge fund leverage. All the regressions in Table 6 include the macro predictors used in Table 5 which are not reported as they have the same signs, same significance levels, and approximately the same magnitudes, as the coefficients reported in the macro-only regressions of Table 5.

The main surprising result of Table 6 is that, with one exception, all of the fund-specific variables have insignificant coefficients. This is for both the case of the bivariate regressions (1)-(4), where the fund-specific variables are used together with past leverage, and in the case of the joint regression (5). This occurs for all three measures of leverage in Panels A-C. Moreover, the adjusted R^2s of the macro-only specifications in Table 5 are almost identical to their counterparts in the fund-specific variable specifications in Table 6. This finding suggests that hedge funds exhibit a high degree of similarity in their leverage exposures that depends largely only on the aggregate state of the economy. Said differently, predictable changes in hedge fund leverage are mostly systematic and there are few fund-level idiosyncratic effects.[15]

[15] Our filters remove young hedge funds which tend to be smaller and tend to have higher funding costs. Thus, our data filters may account for the lack of a relation between AUM and hedge fund leverage. The lack of a relation

The only fund-specific variable that has a posterior t-statistic larger than two is hedge fund return volatility. In Panel A for gross leverage, this variable has a coefficient of -1.41 in the joint regression (5) with a posterior t-statistic of -2.11. The bivariate regression (2) also has a similar coefficient on fund-specific volatility of -1.34 with a posterior t-statistic of -1.93. In the deleveraging cycles of Brunnermeier and Pedersen (2009) and others, fund return volatility affects margins and since margins correspond to limits in leverage, increases in fund return volatility should lead to lower leverage levels of hedge funds. Thus, our findings confirm the prediction of Brunnemeier and Pedersen of a significantly negative coefficient on return volatility. This is essentially the only significant fund-specific effect and it occurs only for gross leverage.

5.4 Contemporaneous Relations with Hedge Fund Leverage

We now investigate the contemporaneous relations of gross leverage in the model in equation (3) with macro and fund-specific variables. Table 7 reports the regression coefficients of the contemporaneous model (3) and compares them with the predictive model (2), which are identical to regression (9) of Table 5 for the macro-only predictors and regression (5) of Table 6 for the fund-specific predictors.

The contemporaneous model has significantly lower adjusted R^2s than the predictive model, at 0.08 vs. 0.13 for the macro-only system and 0.09 vs. 0.13 for the fund-specific variable system. Thus, the fit of the contemporaneous model without lagged leverage is worse than the predictive system with lagged leverage. Hence, the lagged leverage coefficient is an extremely important predictor. The contemporaneous model does have significantly autocorrelated error terms, with estimates of ϕ_ϵ of 0.25 and 0.55 for the macro-only and fund-specific variable cases, respectively. As a specification check, we compute the autocorrelation of error terms in the predictive specification. This turns out to be 0.03. Thus, absorbing the persistence of leverage by past leverage on the RHS absorbs most of the serial correlation effects – when lagged leverage is included as a regressor, there seems to be little gained by making the error terms autocorrelated.

between past flows and leverage may be due to notice period, lockups, and gates restrictions (see, for example, Ang and Bollen, 2010), which give managers advance notice of flows before they actually occur.

Table 7 shows two major differences in sign between the predictive model coefficients and the contemporaneous determinants of leverage in the macro-only specification. First, the coefficient on the S&P500 return is positive at 0.67 in the predictive model and negative at -0.94 in the contemporaneous model. As the stock market increases, leverage contemporaneously decreases – by definition as asset values increase. But, higher stock returns in the past forecast that hedge fund leverage will increase in the future.

Second, the coefficient on LIBOR is contemporaneously positive, at 3.44, but insignificant, in the contemporaneous model compared to a significantly negative coefficient of -6.66 in the predictive model. We expect the coefficient to be negative, which it is in the predictive regression. The unexpected positive sign in the contemporaneous model could be due to lack of power or the fact that true funding costs could have much shorter duration and be more variable than LIBOR. The LIBOR interest rate is, of course, a valid predictor even though it may be an inferior instrument to proxy for leverage costs in a contemporaneous model.

The coefficient on VIX and on aggregate hedge fund flows have the same sign in the predictive and contemporaneous systems, but while their effects are statistically insignificant in predicting hedge fund leverage, they are significantly contemporaneously correlated. In the contemporaneous model, VIX has a coefficient of -1.43 with a posterior t-statistic of -4.79. When VIX increases it is well known that asset prices fall (the leverage effect), which accounts for the negative contemporaneous coefficient. This finding is also consistent with the prediction of Fostel and Geanakoplos (2008), among others, where leverage decreases during times of high volatility. It is also consistent with hedge funds increasing (decreasing) leverage during less (more) volatile times to achieve a desired target level of volatility. As a predictor, the forecasting ability of VIX for future leverage is largely subsumed by lagged leverage as a regressor. The finding that aggregate hedge fund flows are contemporaneously correlated with hedge fund leverage goes against Stein (2009), who predicts that the entry of new capital should decrease the leverage of arbitrageurs.

The last two columns of Table 7 report coefficients for fund-specific variables for the predictive and contemporaneous systems, where both estimations control for the macro variables. The results are similar. The only significant variable in both cases is the fund's rolling 12-month volatility of returns. The effect, however, is much stronger contemporaneously (with a coefficient of -4.35 and a posterior t-statistic of -2.35) compared to the predictive model (with a coefficient of -1.41 with a posterior t-statistic of -2.11). While the negative forecasting ability of fund-specific volatility for future leverage is consistent with deleveraging cycle models, the contemporaneous relation is even stronger. Like the effect of VIX, this may be a reflection of the leverage effect, but it is also consistent with hedge funds using leverage to target a desired level of volatility.

5.5 Hedge Fund Leverage vs. Finance Sector Leverage

In this section we compare hedge fund leverage to the leverage of listed financial companies. We focus on aggregate gross hedge fund leverage, but our previous results show that the net and long-only leverage ratios exhibit similar patterns both for all hedge funds and within hedge fund sectors. We define the leverage of listed firms as the value of total assets divided by market value, that is we study market leverage. Other authors studying the leverage of financial institutions like Adrian and Shin (2009, 2010), among others, use book leverage rather than market leverage. We use market leverage because the market equity value is closest to the NAV of a hedge fund (see Appendix A). We compare hedge fund leverage to the leverage of banks, investment banks, and the entire finance sector, which we describe in more detail in Appendix B.[16]

Figure 7 plots the average level of gross hedge fund leverage in the solid line using the left-hand scale and plots the leverage of the financial sectors in various dashed lines on the right-hand scale. The level of gross hedge fund leverage is the same as in Figure 4 and starts to decline in mid-2007. Gross hedge fund leverage is modest, between 1.5 and 2.5, compared to the leverage of listed financial firms: the average leverage of investment banks and the whole finance sector over our sample are 14.2 and 9.4, respectively. Figure 7 shows that leverage in each of the banking and investment banking subsectors and the whole finance sector are highly correlated. Finance sector leverage starts to rise when hedge fund leverage starts to fall in 2007, continues to rise in 2008, and then shoots up in early 2009 before reverting back to more normal

[16] He, Khang, and Krishnamurthy (2010) contrast the behavior of commercial and investment bank leverage and show they are different. However, many investment banks were either acquired or became commercial banks during the financial crisis. Since our focus is on hedge fund leverage, we choose to contrast hedge fund leverage with the leverage of all of these institutions.

levels in late 2009. This counter-cyclical behavior of financial leverage, where market leverage increases during bad times, is consistent with the model of He and Krishnamurthy (2009).[17]

The remarkable takeaway of Figure 7 is that hedge fund leverage is counter-cyclical to the market leverage of financial intermediaries. As hedge fund leverage declines in 2007 and continues to fall over the financial crisis in 2008 and early 2009, the leverage of financial institutions continues to inexorably rise. The highest level of gross hedge fund leverage is 2.6 at June 2007, well before the worst periods of the financial crisis. In contrast, the leverage of investment banks is 10.4 at June 2007 and severely spikes upward to reach a peak of 40.7 in February 2009. During this month, the U.S. Treasury takes equity positions in all of the major U.S. banks. In contrast, hedge fund leverage is very modest at 1.4 at that time. Note that hedge fund leverage started to decline at least six months before the financial crisis began in 2008.

We document the counter-cyclical behavior of hedge fund leverage to finance sector leverage more completely in Table 8. We report correlation matrices of gross, net and long-only hedge fund leverage in Panels A-C, respectively, with banks, investment banks, and the finance sector. These correlations are very negative. For example, the correlations of gross leverage for all hedge funds with the finance sector are -0.88, -0.82, and -0.88 for banks, investment banks, and the finance sector, respectively. The correlations are very similar for each listed finance sector. The correlations between financial firms and hedge funds are also highly negative for each hedge fund strategy. Clearly, hedge fund leverage moves in the opposite way during the financial crisis to the leverage of regulated and listed financial intermediaries.

There are at least two explanations for the counter-cyclical behavior of hedge fund leverage with respect to listed financial intermediary leverage. First, hedge funds voluntarily reduced leverage much earlier than banks as part of their regular investment process of searching for trades with excess profitability and funding them. An alternative explanation is that the reduction of hedge fund leverage was involuntary. Hedge funds often obtain their leverage through prime brokers which are attached to investment banks and other financial firms. The change in hedge fund leverage could be caused by the suppliers of leverage to hedge funds curtailing

[17] Other authors like Fostel and Geanakoplos (2008), Adrian and Shin (2009, 2010), and Shleifer and Vishny (2010) emphasize the pro-cyclicality of leverage. Many of these authors focus on accounting or book leverage rather than market leverage. Market leverage increases to very high levels during the financial crisis because stock prices of financial institutions are very low at this time.

funding. Risk managers in the prime brokerage divisions of investment banks may have been prescient in partially forecasting the turbulent periods in 2008 and forced hedge funds to reduce leverage earlier. Only when times were very bad in late 2008 did investment banks adjust their own balance sheet leverage. While this story cannot be refuted, the substantial lead time of 6-8 months, shown clearly in Figure 7, where hedge funds reduced leverage before 2008 makes this unlikely. Furthermore, anecdotal evidence through the Fund's industry contacts suggests that prime brokers were not substantially increasing funding costs in early to mid-2007.

5.6 Hedge Fund vs. Finance Sector Exposure

We last attempt to measure the dynamic total exposure of the hedge fund industry. We do this by multiplying leverage by AUM to obtain an estimate of the total exposure. This exercise is, of course, subject not only to the estimation error of our procedure, but also the measurement error of total hedge fund AUM. Since hedge funds are not required to report, the estimates of aggregated hedge fund AUM in the public databases are probably conservative. Thus, our estimated levels of hedge fund exposure have to be interpreted carefully.

Figure 8 plots total hedge fund exposure by taking the estimated gross leverage across hedge funds and aggregated hedge fund AUM reported from the Barclay Hedge database. In the top panel, we plot hedge fund exposure in the solid line (left-hand scale) and hedge fund AUM in the dashed-dot red line (right-hand scale) in trillions of dollars. The correlation between the two series is 0.83. Both AUM and exposure increase over 2006 and 2007 and start falling after June 2008. The total hedge fund exposure starts the sample in January 2005 at $2.5 trillion, steadily increases, and then drops from a peak of $4.9 trillion in June 2008 to a low of $1.7 trillion in March 2009. This decrease represents an overall drop of 65% from peak. The correlations of hedge fund AUM and total exposure with gross leverage are only 0.08 and 0.61, respectively. Note that the decrease in hedge fund leverage from 2007 to 2009 is from around 2.3 to 1.5. Thus, hedge fund exposure is primarily driven by AUM and the dramatic fall in total hedge fund exposure over the financial crisis is caused by investors withdrawing capital from the hedge fund sector. While many studies emphasize the role of leverage cycles, Figure 8 highlights that inflows and outflows are important components of determining total exposure for hedge funds.

The bottom panel of Figure 8 plots the total exposure and market value for investment banks for comparison. Exposure is defined as the total amount of assets held on the balance sheet. Investment bank and hedge fund exposure have similar patterns in the top and bottom panels of Figure 8 and have a high correlation of 0.8. There is a sharp drop in investment bank assets in March 2009 which is due to large writedowns in balance sheets during this quarter. Total assets of investment banks decreased from \$6.9 trillion in early 2008 to a low of \$3.8 trillion in February 2009. Towards the end of the sample assets rebounded to \$5.2 trillion as financial markets stabilized.

We graph the relative exposure of hedge funds to investment banks and the finance sector in Figure 9, which is measured as the ratio of hedge fund exposure to total assets for each of the investment banks and finance sector. The ratio of hedge fund exposure to investment banks (the finance sector) is approximately 65% (30%) until early 2008. Then, the events of the financial crisis in 2008 cause hedge fund exposure to decline to 40% and 15% of the total asset base of investment banks and the finance sector, respectively. Thus, total exposure of hedge funds is modest compared with the exposure of listed financial intermediaries, especially recently after the financial crisis, and it is modest even before the start of the financial crisis in mid-2007.

6 Conclusion

This paper presents, to our knowledge, the first formal analysis of hedge fund leverage using actual leverage ratios. Our unique dataset from a fund-of-hedge funds provides us with both a time series of hedge fund leverage from December 2004 to October 2009, which includes the worst periods of the financial crisis, and a cross section to investigate the determinants of the dynamics of hedge fund leverage. We uncover several interesting and important results.

First, hedge fund leverage is fairly modest, especially compared with the listed leverage of broker/dealers and investment banks. The average gross leverage (including long and short positions) across all hedge funds is 2.1. While there are some funds with large leverage, well above 30, most hedge funds have low leverage partly due to most hedge funds belonging to the equity sector where leverage is low. Gross leverage for other hedge fund sectors like relative value is higher, at 4.8, over the sample.

Second, hedge fund leverage is counter-cyclical to the market leverage of listed financial intermediaries. In particular, hedge fund leverage decreases prior to the start of the financial crisis in mid-2007, where the leverage of investment banks and the finance sector continues to increase. At the worst periods of the financial crisis in late 2008, hedge fund leverage is at its lowest while the leverage of investment banks is at its highest. We find that the dispersion of hedge fund leverage does not markedly change over the financial crisis and that the leverage of each hedge fund sector moves in a similar pattern to aggregate hedge fund leverage. However, we find that the total exposure of hedge funds is similar to the total exposure of investment banks even though the behavior of leverage is different. The main reason for this similar behavior is not the change in hedge fund leverage, but the withdrawal of assets from the hedge fund industry during 2008.

Third, we find that the predictability of hedge fund leverage is mainly from economy-wide, systematic variables. In particular, decreases in funding costs as measured by LIBOR, interest rate spreads, and the cost of default protection on investment banks predict increases in hedge fund leverage over the next month. Increases in asset prices measured by lagged market returns also predict increases in hedge fund leverage. We find the only fund-specific variable significantly predicting hedge fund leverage is return volatility, where increases in fund return volatility tend to reduce leverage. There is little evidence that hedge fund leverage changes are predictable by hedge fund flows or assets under management. Contemporaneously, hedge fund leverage decreases when VIX or fund-specific volatility increase and hedge fund leverage is positively related to aggregate hedge fund flows.

An interesting direction for the future work is to study hedge fund leverage and returns, since in theory when managers perceive better investment opportunities, they should increase leverage. Thus, leverage levels can provide a crude measure of a hedge fund manager's market outlook. Existing empirical work finds little relation at an unconditional level between leverage and returns at the stock level (see, e.g., Bhandari, 1988; Fama and French, 1992), which may be due to not accounting for endogenous leverage and investment choices. Hedge funds are a good laboratory to examine the relation between dynamic leverage management and returns because the underlying asset returns are more easily measured than the asset returns of corporations.

Appendix

A Examples of Hedge Fund Leverage

In order to illustrate how our definitions of leverage differ for various portfolios, we present several simple examples of highly stylized hedge funds. In all our examples, we assume no fees are paid so the gross value of the fund is the same as the net value of the fund. All the transactions are done instantaneously and we report the overall balance sheet of the fund at the same date. For simplicity assume there is only one share so the NAV per share is the same as the AUM of the fund.

Example 1: Long-Only Fund

Consider a hedge fund that has just obtained \$10 in cash from investors. The hedge fund manager purchases securities worth \$10. In addition, the hedge fund manager borrows \$50 and invests those proceeds in a \$50 long securities position. The NAV of the hedge fund is the difference between the long and short positions, which is \$10, and is the same as the initial investment by investors. The balance sheet of the hedge fund after these transactions can be represented by:

Long Assets	Short Assets
\$60 Long Securities	\$50 Borrowed Cash
	\$10 NAV

In this case, the hedge fund has \$60 of Long Securities and \$0 of Short Securities on its balance sheet. As a result, gross leverage is $60/10 = 6$, net leverage is $60/10 = 6$, and long-only leverage is also 6. All these leverage measures coincide because there are no risky asset short positions and the long positions are levered by short cash positions.

Note that an unlevered long-only fund, which holds long asset positions between zero and one together with cash, has positive leverage ratios less than one. All three leverage ratios – gross, net, and long-only – also coincide. In comparison, a corporate finance definition of leverage where assets are the sum of debt and equity would result in a zero leverage measure. This is because cash is counted as an asset on corporate balance sheets, but in our leverage definitions only risky assets are included in the leverage measures.

Example 2: Dedicated Long-Short Fund

Suppose a fund with an initial cash endowment of \$10 uses that cash to purchase a \$10 long security position. In addition, the fund places \$50 in long-short bets in risky assets. The balance sheet of the fund is:

Long Assets	Short Assets
\$60 Long Securities	\$50 Short Securities
	\$10 NAV

In this case, gross leverage is $(60 + 50)/10 = 11$, net leverage is $(60 - 50)/10 = 1$ and long-only leverage is $60/10 = 6$. Now all three leverage measures are different because of the presence of the active short position. In particular, the active short bet in this example induces the marked difference between gross and net leverage.

Example 3: General Levered Fund

Consider a fund with the following balance sheet:

Long Assets	Short Assets
\$20 Long Securities	\$8 Short Securities
	\$2 Borrowed Cash
	\$10 NAV

In this example the fund obtains leverage by both a short cash position as well as a short position in risky assets. The gross leverage is $(20 + 8)/10 = 2.8$, net leverage is $(20 - 8)/10 = 1.2$, and long-only leverage is $20/10 = 2$. In this example the long position is leveraged by both short security positions, which could be active bets or passive hedges, and a short cash position. Note that whereas net leverage in Example 2 is equal to one, the combination of short risky and cash positions causes net leverage to be different from one.

Example 4: Dedicated Short Fund

Our final example is a dedicated short fund. The fund starts with \$10 cash, which it pledges as a collateral to borrow \$50 worth of assets. This represents a margin (haircut) of 20%. The proceeds from selling the securities result in cash received by the fund. These positions represent \$60 of cash on the asset side of the balance sheet and \$50 of short securities on the liability side of the fund's balance sheet:

Long Assets	Short Assets
\$60 Long Cash	\$50 Short Securities
	\$10 NAV

In this case, the hedge fund has \$0 of Long Securities and \$50 of short securities on its balance sheet. Hence, the fund's gross leverage is $(0 + 50)/10 = 50/10 = 5$, the net leverage is $(0 - 50)/10 = -50/10 = -5$, and the long-only leverage is $0/10 = 0$. In the case when net leverage is negative the fund is said to be net short, otherwise it is said to be net long. Since the fund is taking only active short positions, the leverage on the long-side of the balance sheet is zero.

In the case of a fund buying or selling derivative securities instead of transacting in the physical or cash market, the previous examples hold if the derivatives are decomposed into underlying, but time-varying, positions in physical assets and risk-free securities at the reporting date. At a given time, once the derivatives are decomposed into replicating positions in underlying securities, the same leverage calculations can be performed.

B Macro Data Sources

This appendix describes data sources of the macro variables and the construction of leverage for investment banks, bank holding companies, and the financial sector.

B.1 Macro Variables

The list of macro variables is:

Investment Bank (IB) CDS Protection. We take credit default swap (CDS) spreads on 10-year senior bonds of the following institutions, with tickers in parentheses: Bear Stearns (BSC), Citigroup (C), Credit Suisse (CS), Goldman Sachs (GS), HSBC (HBC), JP Morgan (JPM), Lehman Brothers (LEH), Merrill Lynch (MER), and Morgan Stanley (MS). While several of these firms are mainly commercial banks with relatively small investment banking and proprietary trading activities compared to other firms in the list, we take these firms as representative of broker/dealer and investment banking activity. Merrill Lynch and Bear Stearns ceased to be independent entities in the sample and Lehman Brothers entered bankruptcy. Data on CDS prices are obtained from Bloomberg and market weights are taken from CRSP. The CDS contract is specified so that a buyer of protection pays premiums specified in percentage points per annum of a notional contract amount to a seller of protection. If the credit event (default) occurs, then the seller of protection has to deliver the underlying bond to the buyer of protection. We take CDS on 10-year senior bonds of the listed financial institutions. We market weight the CDS spreads using market capitalization data on common equity for those firms in existence at a given point in time.

Investment Bank (IB) Returns. We take monthly total returns on the investment banks from CRSP. These are market value weighted.

S&P 500 Returns. This is the total return on the S&P 500 index taken from Standard & Poor's Index Services.

VIX. This is the monthly level of the VIX volatility index taken from Yahoo Finance.

LIBOR. We obtain the three-month LIBOR rate from Bloomberg.

TED Spread. The TED spread is the difference between the three-month LIBOR yield and the three-month T-bill yield. We obtain the three-month T-bill rate from the St. Louis Fed.

Term Spread. The term spread is defined to be the difference between the 10-year Treasury yield and the three-month T-bill. These are obtained from the St. Louis Fed.

Aggregate Hedge Fund Flows. This is the past three-month flow on the aggregate hedge fund industry, at a monthly frequency, constructed from the Barclays Hedge fund database. This is computed following Section 3.2.2.

B.2 Financial Sector Leverage

We construct leverage for investment banks (BSC, C, CS, GS, HBC, JPM, LEH, MER, and MS), bank holding companies, and the entire financial sector using CRSP and COMPUSTAT data. Bank holding companies are defined as U.S.-based institutions with SIC codes which fall between 6000 and 6199. We define the financial sector as all U.S.-based companies with SIC codes between 6000 and 6299.

Leverage for the listed financial sub-sectors is defined to be:

$$\frac{\sum_{i \in \text{subsector}} A_{i,t}}{\sum_{i \in \text{subsector}} MV_{i,t}} \tag{B-1}$$

for firm i at time t, $MV_{i,t}$ is the company i's market value obtained from CRSP as the product of number of shares outstanding and the closing price at the end of the month t, and $A_{i,t}$ is the total assets of the company obtained from COMPUSTAT. The assets are reported quarterly and we use the most recent, observable quarterly balance sheet report. Note that $A_{i,t}/MV_{i,t}$ is the market leverage of company i using the market value of common stock as the value of equity.

C Examples of Reported Hedge Fund Leverage

Hedge funds report their leverage to investors in several formats, often with several measures of leverage. First, hedge funds periodically send their investors risk reports which list performance and risk statistics over the last reporting period. Table A-1 provides an extract of a risk exposure report from an actual hedge fund. This fund breaks down its exposure into different sectors and reports a gross leverage of 1.11, a net leverage of 0.22, and a long-only leverage of 0.66. This fund reports both long and short positions in each sector. These numbers are received by the Fund every reporting period.

Second, some hedge funds report leverage information in investor letters. An extract of an actual letter is:

> *We made 5.3% on the short book and lost 3.3% on the long book. Having started the month with 7% net long position, we were by mid-month slightly net short for the first time in the fund's history. Around mid-month we suspected that the market falls, triggered by subprime losses in the financial system, were coming to an end and decided to rebuild a modest 18% net long position, which is where we ended the month.*

From the text of the investor letter, we observe that net leverage at the end of the month is 0.18, but gross leverage and long-only leverage are not reported. However, the Fund is able to obtain more details on leverage, and other risk and performance characteristics of each hedge fund than reported in the investor letters by having analysts visit or call the funds to obtain further information. Thus, although the hedge fund officially does not report size of long and short exposure at this month, our dataset contains this information.

D Estimation

This appendix describes the conditional distributions used in the Gibbs sampler. We treat the unobserved data variables as additional parameters using data augmentation. A textbook exposition of these procedures is Robert and Casella (1999).

D.1 Predictive Model

We rewrite the predictive model as:

$$Y_{i,t+1} = c_i + \beta_1 \cdot Y_{i,t} + \beta_2 \cdot X_{i,t} + \varepsilon_{i,t+1}, \tag{D-1}$$

where $Y_{i,t}$ is leverage of fund i at time t, the vector $X_{i,t}$ includes both fund-specific variables and economy-wide variables, and $\varepsilon_{i,t} \sim N(0, \sigma^2)$ and is IID across funds and time. The constant terms, c_i, captures fund-fixed effects. We are especially interested in the predictive coefficients, $\beta = (\beta_1 \, \beta_2)$.

We cast the model in equation (D-1) into a measurement equation:

$$Y^*_{i,t+1} = Y_{i,t+1} + w_{i,t+1}, \tag{D-2}$$

where each observation error in $\{w_{i,t+1}\}$ is equal to zero if $Y_{i,t+1}$ is observed and if $Y_{i,t+1}$ is unobserved is distributed as $N(0, \sigma^2_w)$, where the measurement error is IID across funds and time and is orthogonal to $\varepsilon_{i,t+1}$. This extreme form of measurement error follows Sinopoli et al. (2004) and others and effectively eliminates observations which are observed from the set of measurement equations. This allows us to use a Kalman filter, with extreme heteroskedasticity, in the estimation (see below). We denote

$$\sigma^2_v = \sigma^2 + \sigma^2_w,$$

which is the total variance for observations where leverage is not reported.

We denote the parameters $\theta = (\beta\, \sigma^2\, \sigma^2_v)$ and partition the data $Y = \{Y_{i,t}\}$ and $X = \{X_{i,t}\}$ into observed and unobserved sets, $X = \{X^{obs}\, X^{unobs}\}$ and $Y = \{Y^{obs}\, Y^{unobs}\}$, where we denote the unobserved data with "unobs" superscripts. The set of observed data we denote as $\mathcal{Y} = \{X^{obs}\, Y^{obs}\}$. We use θ_- to denote the set of parameters less the parameter currently being drawn.

The set of conditional distributions in the Gibbs sampler is:

$p(\beta, c_i|\theta_-, \mathcal{Y}, X^{unobs}, Y^{unobs})$

Conditional on X^{unobs} and Y^{unobs} being observed, equation (D-1) is a regular OLS regression and we can use a conjugate Normal draw. The dependent variable has two variances: if the regressor is observed in data the residuals have variance σ^2 and if the regressor is unobserved in data the residual variance is σ^2_v. Thus, we can rewrite equations (D-1) and (D-2) as

$$Y = X\beta + V, \tag{D-3}$$

where $Y = \{Y_{i,t+1} - c_i\}$, $X = \{Y_{i,t}\, X_{i,t}\}$, and $V \sim N(0, \Sigma)$, where Σ is a diagonal covariance matrix with entries σ^2 or σ^2_v depending on whether the regressor is observed in data or not.

We estimate the fixed effects in each iteration by appropriately demeaning both sides of equation (D-3). For fund-fixed effects we subtract average values of the left-hand side and right-hand side variables for the observations that correspond to that fund. The fixed effects change in each iteration because the missing Y^{unobs} and X^{unobs} are updated.

$p(\sigma^2, \sigma^2_v|\theta_-, \mathcal{Y}, X^{unobs}, Y^{unobs})$

We draw σ^2 using a conjugate Inverse Gamma distribution given the regression (D-3) taking only the entries where the residual variance is σ^2. We can draw $\sigma^2_v = \sigma^2 + \sigma^2_w$ by taking the entries where the residual variance is σ^2_v. We ensure that $\sigma^2_v > \sigma^2$ in each draw.

$p(Y^{unobs}|\theta, \mathcal{Y}, X^{unobs})$

We can interpret the system for $Y_{i,t}$ as a state equation (D-1) and a measurement equation (D-2). This allows us to use a FFBS draw following Carter and Kohn (1994), except with (extreme) heteroskedasticity and exogenous variables. For notational simplicity, we suppress dependence on fund i below and use a FFBS draw separately on each fund i with missing values.

We run the Kalman filter to determine the conditional distributions of the unobserved variables,

$$Y_{t|t-1} \sim N(\mu_{t,t-1}, V_{t,t-1}),$$

where $Y_{t|t-1}$ is Y_t conditional on the history of observations up to and including $t-1$, which we denote as H_{t-1},

$$\mu_{t,t-1} = c + \beta_1 Y^*_{t-1} + \beta_2 X_{t-1}$$

and

$$V_{t,t-1} = \beta_1^2 V_{t-1,t-1} + \sigma^2,$$

treating the X_t values as exogenous.

When Y_t^* is added to the history, we have the joint distribution

$$\begin{pmatrix} Y_t \\ Y_t^* \end{pmatrix} \sim N\left(\begin{pmatrix} \mu_{t,t-1} \\ \mu_{t,t-1} \end{pmatrix}, \begin{pmatrix} V_{t,t-1} & V_{t,t-1} \\ V_{t,t-1} & V_{t,t-1} + \sigma_w^2 \end{pmatrix} \right). \tag{D-4}$$

Note that $\sigma_w^2 = 0$ if Y_t is observed. From the moments of a partitioned normal, we have

$$Y_{t|t} = Y_t | Y_t^*, H_{t-1} \sim N(\mu_{t,t}, V_{t,t}), \tag{D-5}$$

where

$$\mu_{t,t} = \mu_{t,t-1} + \frac{V_{t,t-1}}{V_{t,t-1} + \sigma_w^2}(Y_t^* - \mu_{t,t-1}),$$

and

$$V_{t,t} = V_{t,t-1} - \frac{V_{t,t-1}^2}{V_{t,t-1} + \sigma_w^2} = \frac{V_{t,t-1}\sigma_w^2}{V_{t,t-1} + \sigma_w^2}.$$

Note that if $\beta_2 = 0$ this simplifies to a regular Kalman filter. We assume the initial distribution is

$$y_1 \sim N\left(\frac{c + \beta_2 \mathrm{E}X}{1 - \beta_1}, \frac{\sigma^2}{1 - \beta_1^2} \right),$$

which is the stationary distribution for Y_t assuming X_t is exogenous. We update as per a normal Kalman filter to obtain the distribution $y_{T|T}$ and the smoothed conditional values $y_{t|T}$. Once the Kalman filter is run forwards, we backwards sample following Carter and Kohn (1994).

$p(X^{unobs} | \theta, \mathcal{Y}, Y^{unobs})$

We assume that the regressand variables, both observed and unobserved, are all jointly normally distributed $N(\tilde{\mu}, \tilde{\Sigma})$. To draw the unobserved variables for fund i at time t, $X_{i,t}^{unobs}$, we have

$$X_{i,t}^{unobs} | X_{i,t}^{obs}, \theta, \mathcal{Y} \sim N(m, v^2), \tag{D-6}$$

where m and v^2 can be obtained by the mean and variance of a partitioned normal where

$$X_{i,t} = (X_{i,t}^{obs}\; X_{i,t}^{unobs}) \sim N(\tilde{\mu}, \tilde{\Sigma})$$

has been partitioned into the observed and unobserved components. A similar procedure is used by Li, Sarkar, and Wang (2003), except we recognize that $Y_{i,t}$ is endogenously persistent.

We update the values $\tilde{\mu}$ and $\tilde{\Sigma}$ each iteration by a conjugate normal distribution and conjugate Wishart draw, respectively.

We estimate with a burn-in period of 1000 observations and 2000 simulations. Convergence is extremely fast. We report in the tables a posterior mean for each parameter and a posterior "t-statistic" which is the ratio of the posterior mean and posterior standard deviation. This is to make inference comparable to a classical OLS estimation, which cannot handle missing observations.

During each iteration we compute adjusted R^2 statistics. We calculate the regular R^2 as

$$R^2 = 1 - \frac{SS_{residual}}{SS_{total}} \tag{D-7}$$

where $SS_{residual}$ denotes the residual sum of square, while SS_{total} denotes the total sum of squares. For our model that predicts values $Y_{i,t}$ by producing estimates $\hat{Y}_{i,t}$, $SS_{residual} = \sum_{i,t}(Y_{i,t+1} - \hat{Y}_{i,t+1})^2$ and $SS_{total} = \sum_{i,t}(Y_{i,t+1} - \bar{Y})^2$, where $\bar{Y}$ is the average value of $Y_{i,t}$ and $\hat{Y}_{i,t+1} = c_i + \beta_1 \cdot Y_{i,t} + \beta_2 \cdot X_{i,t}$ from equation (D-1). We record the adjusted R^2:

$$\text{adjusted } R^2 = 1 - (1 - R^2)\frac{n - k}{n - p - k}. \tag{D-8}$$

where the number of observations is n, the number of funds is k and the number of explanatory variables is p. In the tables, we report the posterior mean of the adjusted R^2 statistic computed in each iteration.

D.2 Contemporaneous Model

The estimation of the contemporaneous model in equation (3) is similar to the predictive model in equation (2), except that we must now account for serial correlation in the error terms. The model is

$$Y_{i,t} = \beta' X_{i,t} + \epsilon_{i,t}, \tag{D-9}$$

where for simplicity we ignore the fund-fixed effects. Fund i's idiosyncratic error term, $e_{i,t}$ follows the AR(1) process

$$\epsilon_{i,t} = \phi_\epsilon \epsilon_{i,t-1} + v_{i,t}, \tag{D-10}$$

where $v_{i,t} \sim N(0, \sigma^2)$. Similar to the predictive model, leverage may be unobserved at time t, so we employ the measurement equation (D-2).

We follow Chib (1993) in recasting equations (D-9) and (D-10) as a regular OLS equation by defining

$$\begin{aligned} \tilde{Y}_{i,t} &= Y_{i,t} - \phi_\epsilon Y_{i,t-1} \\ \tilde{X}_{i,t} &= X_{i,t} - \phi_\epsilon X_{i,t-1}. \end{aligned} \tag{D-11}$$

This allows us to write

$$\tilde{Y}_{i,t} = c_i + \beta' \tilde{X}_{i,t} + v_{i,t}, \tag{D-12}$$

which now has an i.i.d. error term. The corresponding measurement equation is

$$\tilde{Y}^*_{i,t} = \tilde{Y}_{i,t} + w_{i,t}, \tag{D-13}$$

where the observation error variance is $\sigma_v^2 = \sigma^2 + \sigma_w^2$ where $\tilde{Y}_{i,t}$ is unobserved and σ^2 if $\tilde{Y}_t$ is observed.

The set of conditional draws in the Gibbs sampler we use are:

$p(\beta|\theta_-, \mathcal{Y}, Y^{unobs})$

We draw β using a conjugate normal draw from the regression equation (D-12). There are two possible variances, σ^2 in the case $\tilde{Y}_{i,t}$ is observed and σ_v^2 in the case it is unobserved.

$p(\phi_\epsilon|\theta_-, \mathcal{Y}, Y^{unobs})$

Chib (1993) notes that equation (D-10) is a standard regression draw with ϵ_t given by equation (D-9). We draw ϕ_ϵ with a conjugate normal distribution.

$p(\sigma^2, \sigma_v^2|\theta_-, \mathcal{Y}^*, Y^{unobs})$,

We draw σ_v^2 using a conjugate Inverse Gamma distribution from the regression equation (D-12). We ensure that $\sigma_v^2 > \sigma^2$ in each draw.

$p(Y^{unobs}|\theta, \mathcal{Y})$

Same as Section D.1.

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Table 1: Margin Requirements by Security Type

	Margin (Haircut)	Implied Leverage
Treasuries	0.1-3%	33-100
Investment Grade Corp Bonds	5-10%	10-20
High Yield Bonds	10-15%	6.6-10
Convertible Bonds:	15-20%	5-6.6
Equities:	5-50%	2-20
Commodity Futures	10%	10
Financial Futures	3%	33
Foreign Exchange Futures	2%	50
Options (equity)	75%	1.3
Interest Rate Swaps	1%	100
Foreign Exchange Swaps	1%	100
Total Return Swaps	10%	10

The table lists the margin requirements and their implied level of leverage in various security markets. The data is obtained by collating information from prime brokers and derivatives exchanges as of March 2010.

Table 2: Summary Statistics of Data

Panel A: Number of Observations

Strategy	Observations	Funds
Relative Value (RV)	1414	36
Credit (CR)	875	21
Event Driven (ED)	1408	37
Equity (EQ)	4439	114
Total Hedge Funds	8136	208

Panel B: Fund Specific Variables

	Mean	Standard Deviation	Auto-Correlation	% Observed
Observed Gross Leverage	2.130	0.616	0.680	82.0%
Observed Net Leverage	0.587	0.278	0.595	82.0%
Observed Long-Only Leverage	1.360	0.382	0.690	82.1%
Returns	0.003	0.031	0.241	100.0%
Past 12-month Volatility	0.026	0.010	0.828	69.6%
Past 3-month Flows	0.022	0.226	0.620	77.4%
Log AUM	8.528	0.143	0.883	85.0%

Panel A lists the number of observations and number of hedge funds broken down by strategy. Panel B reports summary statistics for the hedge fund variables across all funds. We report means, standard deviation, and autocorrelation of the monthly frequency variables. The means and standard deviation are computed using the full observed data while the autocorrelations are computed only using observations with adjacent months for each fund. We compute the variables for each fund and then report the average across funds for each variable. Hedge fund flows are computed using AUMs and fund returns over the past three months following equation (1). The last column reports the percentage of observations that are observed in the dataset. The data sample is from December 2004 to October 2009.

Table 3: Correlations of Gross, Net, and Long-Only Leverage

	Gross	Net	Long-Only	Gross	Net	Long-Only
Panel A: All Hedge Funds						
Gross	1.000					
Net	0.927	1.000				
Long-Only	0.994	0.962	1.000			
Panel B: Hedge Fund Sectors						
Relative Value				Equity		
Gross	1.000			1.000		
Net	0.876	1.000		0.490	1.000	
Long-Only	0.997	0.910	1.000	0.955	0.725	1.000
Event Driven				Credit		
Gross	1.000			1.000		
Net	0.835	1.000		0.805	1.000	
Long-Only	0.974	0.938	1.000	0.981	0.904	1.000

The table reports correlations of the posterior means of gross, net, and long-only leverage for all hedge funds and for hedge fund sectors at a monthly frequency. The hedge fund leverage ratios consist of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund-fixed effects. The data sample is from December 2004 to October 2009.

Table 4: Cross-Correlations of Hedge Fund Leverage Within Sectors

	All Hedge Funds (HF)	Hedge Fund Strategies: RV	EQ	ED	CR
Panel A: Gross Leverage					
All Hedge Funds (HF)	1.000				
Relative Value (RV)	0.930	1.000			
Equity (EQ)	0.761	0.557	1.000		
Event Driven (ED)	0.846	0.650	0.899	1.000	
Credit (CR)	0.836	0.738	0.853	0.786	1.000
Panel B: Net Leverage					
All Hedge Funds (HF)	1.000				
Relative Value (RV)	0.780	1.000			
Equity (EQ)	0.932	0.695	1.000		
Event Driven (ED)	0.963	0.657	0.857	1.000	
Credit (CR)	0.921	0.578	0.854	0.879	1.000
Panel C: Long-Only Leverage					
All Hedge Funds (HF)	1.000				
Relative Value (RV)	0.923	1.000			
Equity (EQ)	0.866	0.683	1.000		
Event Driven (ED)	0.915	0.736	0.920	1.000	
Credit (CR)	0.877	0.751	0.917	0.857	1.000

The table reports correlations of the posterior means of leverage of hedge funds (HF) and average leverage of their specific strategies (RV, EQ, ED, CR) for each of the definitions of hedge fund leverage: Gross Leverage (Panel A), Net Leverage (Panel B), and Long Only Leverage (Panel C) separately at a monthly frequency. The hedge fund leverage ratios consist of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund-fixed effects. The data sample is from December 2004 to October 2009.

Table 5: Macro Predictors of Hedge Fund Leverage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Gross Leverage									
Past Gross Lev	-0.2446	-0.2228	-0.2250	-0.2423	-0.2378	-0.2288	-0.2401	-0.2347	-0.2447
	[-32.0]	[-28.8]	[-30.7]	[-31.8]	[-30.0]	[-29.5]	[-31.5]	[-30.9]	[-32.0]
IB CDS	-11.49								-9.3278
	[-12.4]								[-3.54]
IB Ret		0.5968							-0.0436
		[6.11]							[-0.26]
S&P 500 Ret			1.3684						0.6750
			[7.68]						[2.09]
VIX				-0.9238					-0.1010
				[-11.9]					[-0.51]
LIBOR					4.3489				-6.6629
					[7.66]				[-2.35]
TED Spread						-15.19			7.5973
						[-8.64]			[1.90]
Term Spread							-6.8214		-10.32
							[-9.54]		[-2.80]
Agg HF Flows								7.7129	0.0934
								[1.15]	[0.38]
Adjusted R^2	0.130	0.118	0.121	0.129	0.120	0.122	0.123	0.120	0.131
Panel B: Net Leverage									
Past Net Lev	-0.3114	-0.2931	-0.3003	-0.3013	-0.3053	-0.2965	-0.3036	-0.2959	-0.3052
	[-3.48]	[-3.75]	[-3.31]	[-4.22]	[-3.61]	[-3.49]	[-3.90]	[-3.86]	[-3.82]
IB CDS	-3.3967								-1.1898
	[-3.69]								[-1.04]
IB Ret		0.2644							0.1340
		[5.88]							[1.83]
S&P 500 Ret			0.5101						0.0784
			[5.92]						[0.57]
VIX				-0.2854					-0.1051
				[-4.83]					[-1.22]
LIBOR					1.4241				0.9969
					[2.75]				[0.85]
TED Spread						-4.5400			-0.7010
						[-4.26]			[-0.43]
Term Spread							-2.0531		0.5129
							[-3.16]		[0.34]
Agg HF Flows								0.3295	-0.0668
								[3.29]	[-0.61]
Adjusted R^2	0.155	0.150	0.151	0.155	0.151	0.149	0.153	0.149	0.156

Table 5 Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel C: Long-Only Leverage									
Past Long Lev	-0.2376	-0.2157	-0.2177	-0.2351	-0.2301	-0.2219	-0.2324	-0.2273	-0.2373
	[-31.2]	[-27.0]	[-29.1]	[-31.3]	[-28.4]	[-29.9]	[-29.4]	[-30.1]	[-29.9]
IB CDS	-6.9342								-4.9876
	[-12.6]								[-3.39]
IB Ret		0.4228							0.0433
		[6.77]							[0.40]
S&P 500 Ret			0.9124						0.3891
			[8.52]						[1.92]
VIX				-0.5741					-0.0918
				[-12.7]					[-0.79]
LIBOR					2.5667				-2.8146
					[7.59]				[-1.58]
TED Spread						-9.4262			3.2221
						[-8.51]			[1.31]
Term Spread							-4.0850		-4.6731
							[-9.48]		[-2.00]
Agg HF Flows								0.6891	0.0152
								[7.81]	[0.10]
Adjusted R^2	0.126	0.116	0.118	0.126	0.116	0.118	0.119	0.117	0.127

The table reports regression coefficients of equation (2) to predict changes in gross leverage (Panel A), net leverage (Panel B), and long-only leverage (Panel C) over the next month. The first row in each panel reports the coefficient on the lagged leverage variable and the other right-hand side variables are all macro variables. Each column reports a different regression. "IB CDS" is the equity market-value weighted cost of CDS protection on defaults on 10-year senior bonds of major investment banks (IB), "IB Ret" is the return on the market-value weighted portfolio of IB common stocks, "S&P500 Ret" is the monthly total return on the S&P500 index, "Agg HF Flows" is the past three-month flow on the aggregate hedge fund industry as reported by Barclay Hedge. All variables are described in detail in Appendix B. The table reports posterior means of coefficients and posterior means of "t-statistics" in square brackets below each coefficient. All estimations have fund fixed effects. Appendix D contains details of the estimation, including the implementation of fixed effects and the calculation of the Adjusted R^2. The data sample is from December 2004 to October 2009.

Table 6: Fund-Specific Predictors of Hedge Fund Leverage

	(1)	(2)	(3)	(4)	(5)
Panel A: Gross Leverage					
Past Gross Lev	-0.2443	-0.2452	-0.2445	-0.2451	-0.2455
	[-30.3]	[-30.5]	[-30.5]	[-30.1]	[-31.1]
Past Ret	-0.1288				-0.2151
	[-0.49]				[-0.82]
12-month Vol		-1.337			-1.4139
		[-1.93]			[-2.11]
3-month Flows			-0.0053		-0.0024
			[-0.21]		[-0.10]
Log AUM				-0.0325	-0.0414
				[-1.13]	[-1.43]
Adjusted R^2	0.130	0.131	0.131	0.131	0.131
Panel B: Net Leverage					
Past Net Lev	-0.3107	-0.3066	-0.3106	-0.3089	-0.3098
	[-3.69]	[-3.99]	[-3.59]	[-3.71]	[-3.62]
Past Ret	-0.2357				-0.2057
	[-1.93]				[-1.64]
12-month Vol		0.1615			0.0543
		[0.51]			[0.18]
3-month Flows			0.0142		0.0153
			[1.35]		[1.49]
Log AUM				-0.0183	-0.0201
				[-1.41]	[-1.45]
Adjusted R^2	0.157	0.156	0.156	0.157	0.157
Panel C: Long-Only Leverage					
Past Long Lev	-0.2371	-0.2372	-0.2373	-0.2381	-0.2375
	[-30.4]	[-32.1]	[-31.1]	[-29.9]	[-30.6]
Past Ret	-0.1923				-0.2258
	[-1.20]				[-1.41]
12-month Vol		-0.6278			-0.7289
		[-1.60]			[-1.76]
3-month Flows			0.0048		0.0045
			[0.33]		[0.31]
Log AUM				-0.0236	-0.0284
				[-1.38]	[-1.60]
Adjusted R^2	0.127	0.127	0.127	0.127	0.127

Note to Table 6

The table reports regression coefficients of equation (2) to predict changes in gross leverage (Panel A), net leverage (Panel B), and long-only leverage (Panel C) over the next month. The first row in each panel reports the coefficient on the lagged leverage variable and the other right-hand side variables are fund-specific and macro variables. Each column reports a different regression. "Past Ret" is the fund's return in the past month, "12-month Vol" is the volatility of the hedge fund's returns computed using monthly data over the past 12 months, "3-month Flows" is the hedge fund flow over the past three months computed using equation (1), and "Log AUM" is the logarithm of each hedge fund's AUM. All the regression specifications also control for the macro predictors used in Table 5: the cost of CDS protection on major investment banks, the return on the market-value weighted portfolio of investment banks, the S&P500 return, option VIX volatility, LIBOR, the TED spread, the term spread, and aggregate hedge fund flows. All variables are described in detail in Appendix B. The table reports posterior means of coefficients and posterior means of "t-statistics" in square brackets below each coefficient. All estimations have fund fixed effects. Appendix D contains details of the estimation, including the implementation of fixed effects and the calculation of the Adjusted R^2. The data sample is from December 2004 to October 2009.

Table 7: Contemporaneous Relations with Gross Hedge Fund Leverage

	Predictive	Contemporaneous		Predictive	Contemporaneous
Macro Variables			Fund-Specific Variables		
Past Leverage	-0.2447		Past Leverage	-0.2455	
	[-32.0]			[-31.1]	
IB CDS	-9.3278	-1.3666	Past Ret	-0.2151	-0.1123
	[-3.54]	[-0.38]		[-0.82]	[-0.35]
IB Ret	-0.0436	-0.2248	12-month Vol	-1.4139	-4.3495
	[-0.26]	[-0.90]		[-2.11]	[-2.35]
S&P 500 Ret	0.6750	-0.9419	3-month Flows	-0.0024	-0.0530
	[2.09]	[-2.02]		[-0.10]	[-1.11]
VIX	-0.1010	-1.4324	Log AUM	-0.0414	0.2552
	[-0.51]	[-4.79]		[-1.43]	[1.75]
LIBOR	-6.6629	3.4420			
	[-2.35]	[0.76]			
TED Spread	7.5973	8.7629			
	[1.90]	[1.49]			
Term Spread	-10.32	-12.237			
	[-2.80]	[-2.09]			
Agg HF Flows	0.0934	1.3419			
	[0.38]	[3.13]			
ϕ_ϵ		0.2494	ϕ_ϵ		0.5547
		[32.9]			[45.5]
Adjusted R^2	0.131	0.080	Adjusted R^2	0.131	0.086

The table reports regression coefficients for macro and fund-specific variables of the "Predictive" model in equation (2) and the "Contemporaneous" model in equation (3) for gross hedge fund leverage. The predictive model coefficients are identical to regression (9) of Table 5 for the macro-only predictors and regression regression (5) of Table 6 for the fund-specific predictors. The "Fund-Specific Variables" regressions control for the macro predictors listed in the "Macro Variables" regressions: "IB CDS" is the equity market-value weighted cost of CDS protection on defaults on 10-year senior bonds of major investment banks (IB), "IB Ret" is the return on the market-value weighted portfolio of IB common stocks, "S&P500 Ret" is the monthly total return on the S&P500 index, "Agg HF Flows" is the past three-month flow on the aggregate hedge fund industry as reported by Barclay Hedge. "Return" is the fund's return in the last month, "12-month Vol" is the volatility of the hedge fund's returns computed using monthly data over the past 12 months including the last month, "3-month Flows" is the hedge fund flow over the past three months including the last month computed using equation (1), and "Log AUM" is the logarithm of each hedge fund's AUM. For the fund-specific variables: "Past Ret" is the fund's return in the past month, "12-month Vol" is the volatility of the hedge fund's returns computed using monthly data over the past 12 months, "3-month Flows" is the hedge fund flow over the past three months computed using equation (1), and "Log AUM" is the logarithm of each hedge fund's AUM. All variables are described in detail in Appendix B. The table reports posterior means of coefficients and posterior means of "t-statistics" in square brackets below each coefficient. All estimations have fund fixed effects. Appendix D contains details of the estimation, including the implementation of fixed effects and the calculation of the Adjusted R^2. The data sample is from December 2004 to October 2009.

Table 8: Correlations of Hedge Fund and Finance Sector Leverage

	All Hedge Funds	Hedge Fund Strategies RV	EQ	ED	CR
Panel A: Gross Leverage					
Banks	-0.884	-0.820	-0.613	-0.774	-0.658
Investment Banks	-0.823	-0.734	-0.536	-0.733	-0.586
Finance Sector	-0.884	-0.812	-0.608	-0.776	-0.656
Panel B: Net Leverage					
Banks	-0.873	-0.623	-0.740	-0.923	-0.772
Investment Banks	-0.845	-0.525	-0.766	-0.891	-0.765
Finance Sector	-0.884	-0.610	-0.764	-0.931	-0.789
Panel C: Long-Only Leverage					
Banks	-0.893	-0.801	-0.735	-0.867	-0.722
Investment Banks	-0.840	-0.712	-0.680	-0.828	-0.667
Finance Sector	-0.896	-0.791	-0.738	-0.872	-0.726

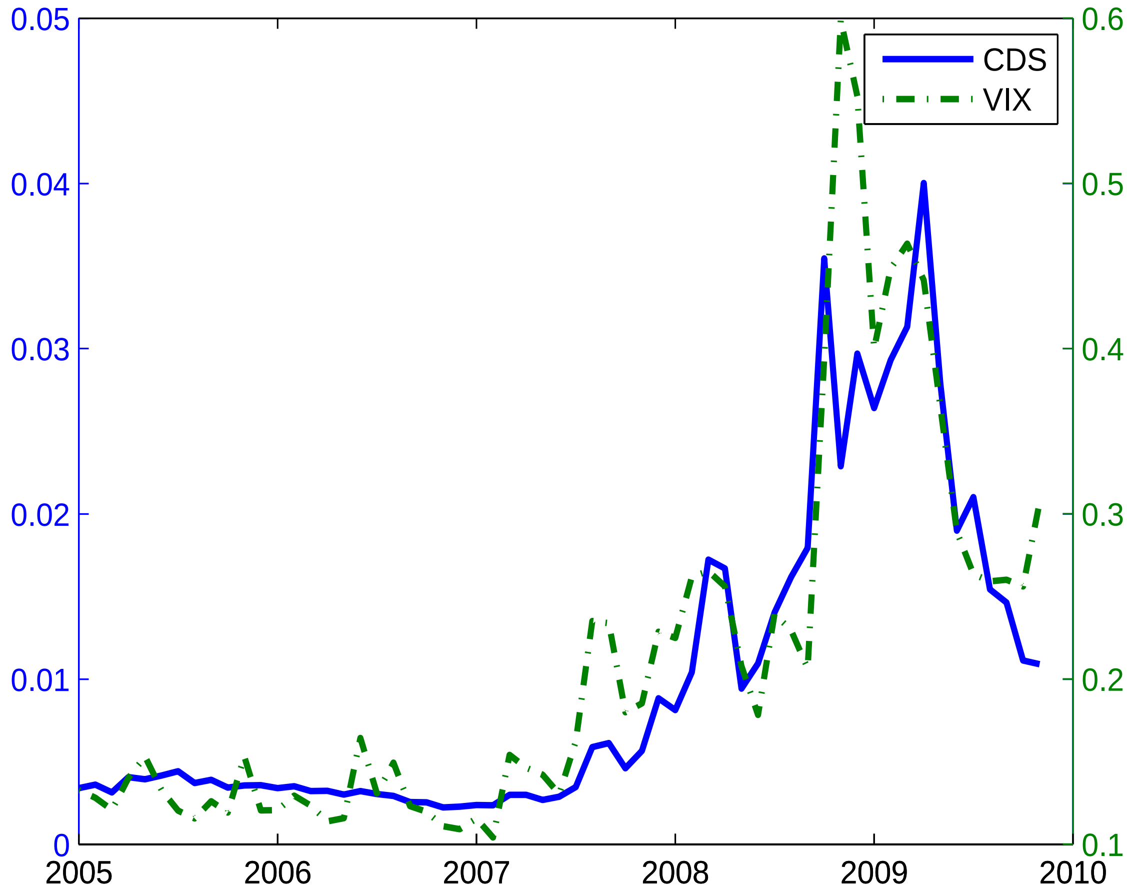
The table reports correlations of average levels of leverage of hedge funds (HF) and average leverage of their specific strategies (RV, EQ, ED, CR) with average leverage of bank holding companies (Banks), Investment Banks (Bear Stearns, Citibank, Credit Suisse, Goldman Sachs, HSBC, JP Morgan, Lehman Brothers, Merrill Lynch, and Morgan Stanley), and the finance sector separately for each definition of hedge fund leverage: Gross Leverage (Panel A), Net Leverage (Panel B), and Long-Only Leverage (Panel C) at the monthly frequency. We compute the leverage of finance subsectors following Appendix B. The leverage of hedge funds is gross leverage and consists of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund-fixed effects. The data sample is from December 2004 to October 2009.

Table A-1: A Sample Hedge Fund Risk Exposure Report

Sector	Gross Leverage Ratio (%)	Net Leverage Ratio (%)	Long Market Value/ Equity (%)	Short Market Value/ Equity (%)
Consumer Discretionary	16.73	1.93	9.33	(7.40)
Consumer Staples	9.08	5.16	7.12	(1.96)
Energy	7.84	(1.91)	2.97	(4.87)
Financials	4.20	(2.87)	0.66	(3.53)
Health Care	5.01	2.17	3.59	(1.42)
Industrials	22.14	7.28	14.71	(7.43)
Information Technology	26.05	5.41	15.73	(10.32)
Materials	1.31	0.46	0.89	(0.43)
Other Assets	17.72	3.76	10.74	(6.98)
Telecommunication Services	0.69	0.28	0.48	(0.21)
Total	110.78	21.68	66.23	(44.55)

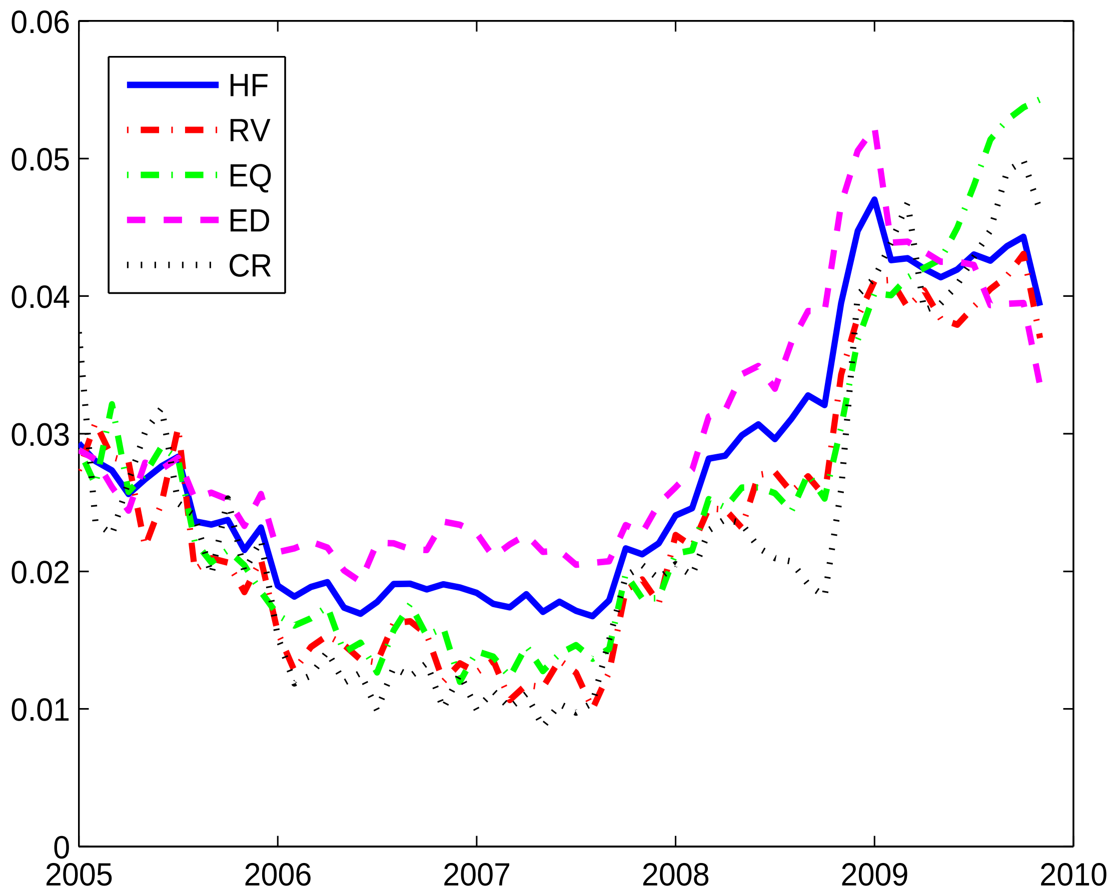
This table shows a sample hedge fund risk exposure report. This fund reports exposures monthly broken down by sector. The reported quantities are percentages of NAV.

Figure 1: VIX and CDS Protection



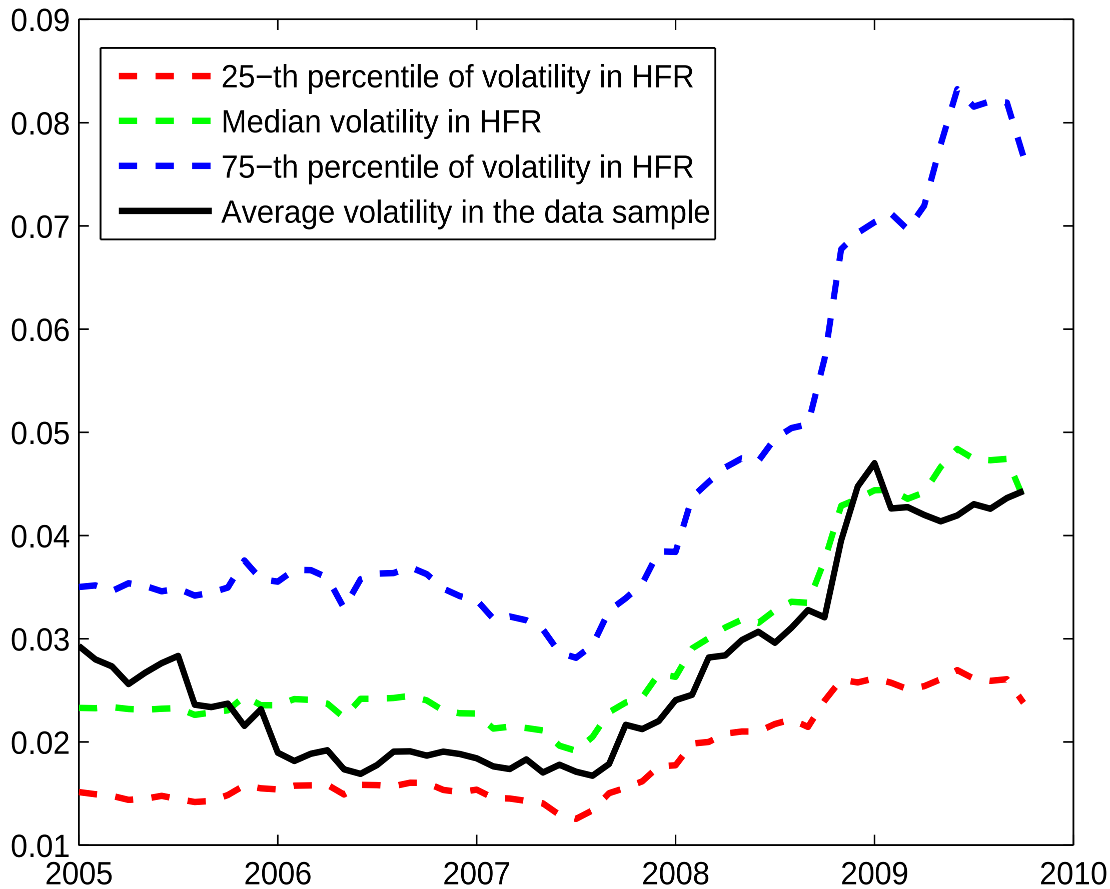
The credit default swap (CDS) cost of protection for the investment banks (Bear Stearns, Citibank, Credit Suisse, Goldman Sachs, HSBC, JP Morgan, Lehman Brothers, Merrill Lynch, and Morgan Stanley) is shown in the solid line with the axis on the left-hand scale. We plot the VIX volatility index in the dotted line on the right-hand scale. The data sample is from December 2004 to October 2009.

Figure 2: Rolling 12-month Hedge Fund Volatilities



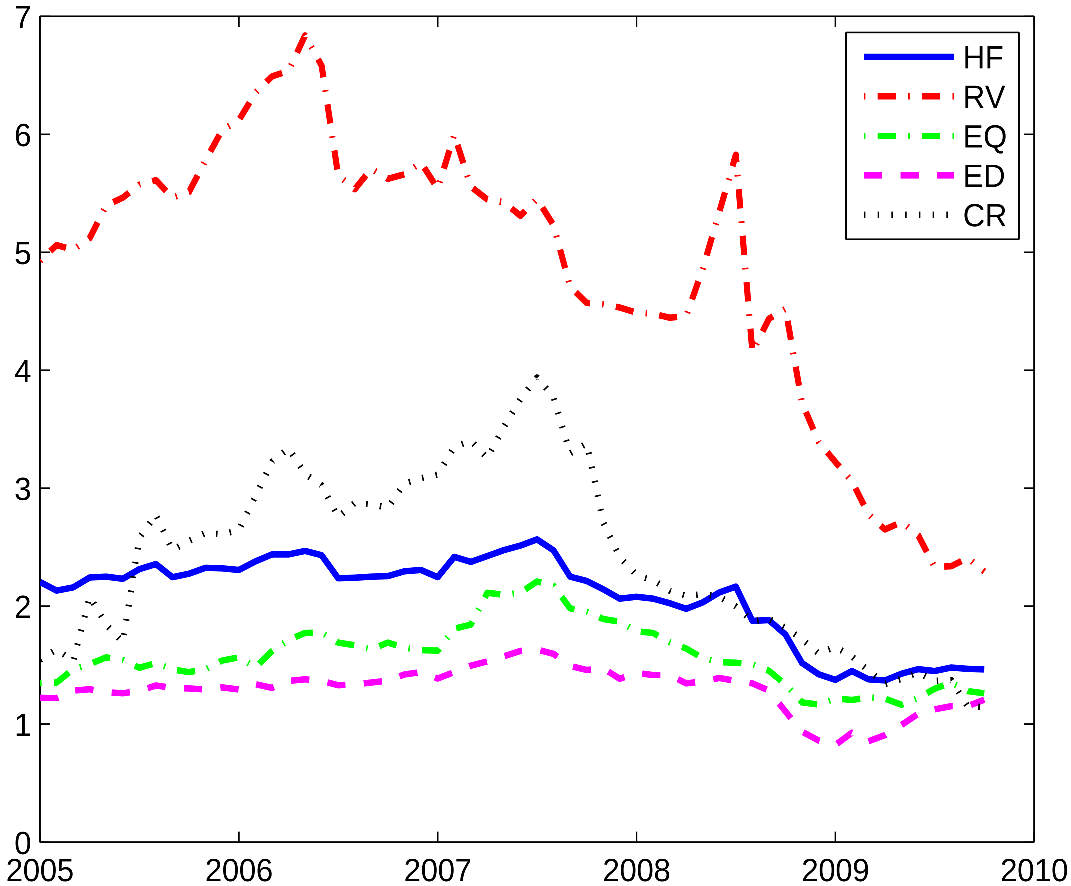
This figure compares volatilities of returns of different hedge fund strategies over the sample period. The monthly volatility for each strategy is constructed as an average value of sample volatilities of returns over the past 12 months for the hedge funds that belong to the strategy. The strategies are relative value (RV), equity (EQ), event driven (ED), credit (CR), and the whole hedge fund sample is denoted HF. The data sample is from December 2004 to October 2009.

Figure 3: Hedge Fund Volatilities vs. HFR Volatilities



We plot 25-th, 50-th and 75-th percentile values of 12-month rolling volatilities of returns of funds in the HFR database and the average 12-month rolling volatility of returns of funds in the Fund's database. The data sample is from December 2004 to October 2009.

Figure 4: Hedge Fund Gross Leverage

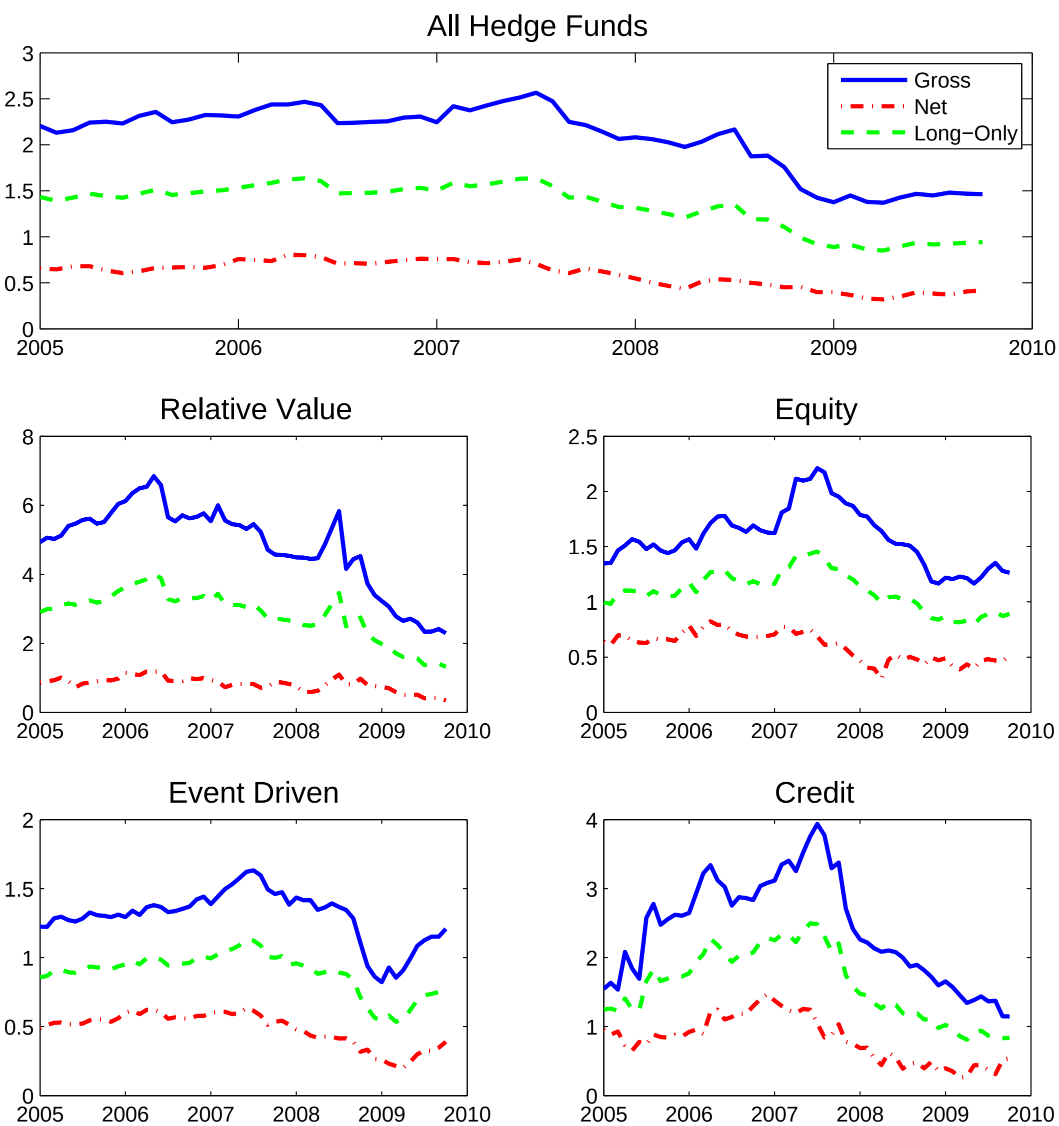


The figure plots hedge fund gross leverage for all hedge funds (HF) and hedge fund sectors. The sectors are relative value (RV), equity (EQ), event driven (ED), and credit (CR). The leverage aggregates all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following the estimation method outlined in Appendix D. These estimates are obtained using the model in equation (2) using all macro and fund-specific variables and fund-fixed effects. The data sample is from December 2004 to October 2009.

Figure 5: Cross-Sectional Dispersion of Gross Hedge Fund Leverage

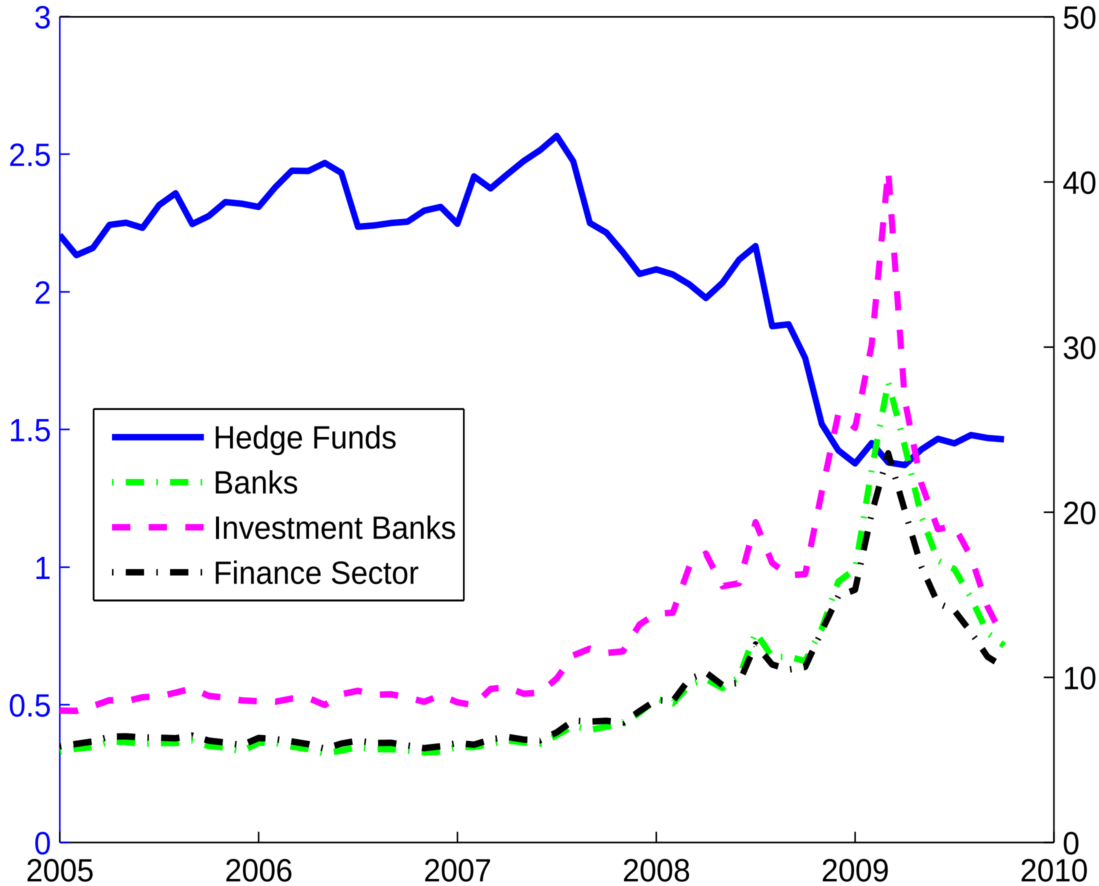
The figure plots the median (solid blue line) together with the 25th and 75th cross-sectional percentiles (dashed green and dashed-dot red lines, respectively) of gross hedge fund leverage across all funds. The hedge fund leverage ratios consist of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund-fixed effects. The data sample is from December 2004 to October 2009.

Figure 6: Gross, Net, and Long-Only Hedge Fund Leverage



The figure shows the dynamics of the posterior means of gross leverage (solid blue line), net leverage (dashed-dot red line), and long-only leverage (dashed green line) for all hedge funds and for hedge fund sectors at the monthly frequency. The hedge fund leverage ratios consist of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund fixed effects. The data sample is from December 2004 to October 2009.

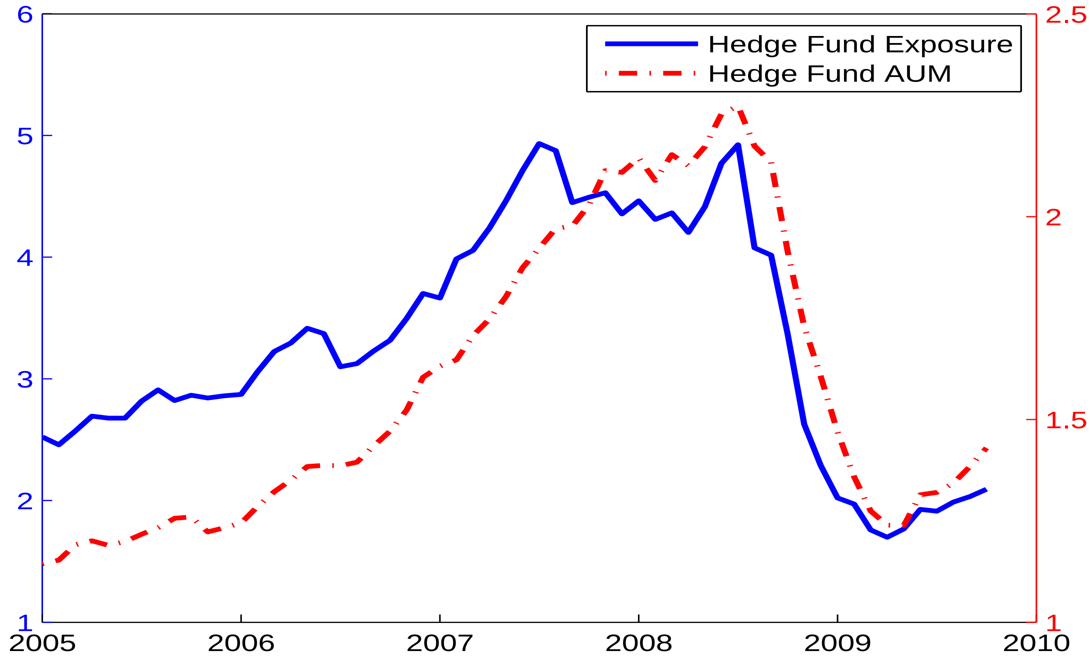
Figure 7: Hedge Fund and Finance Sector Leverage



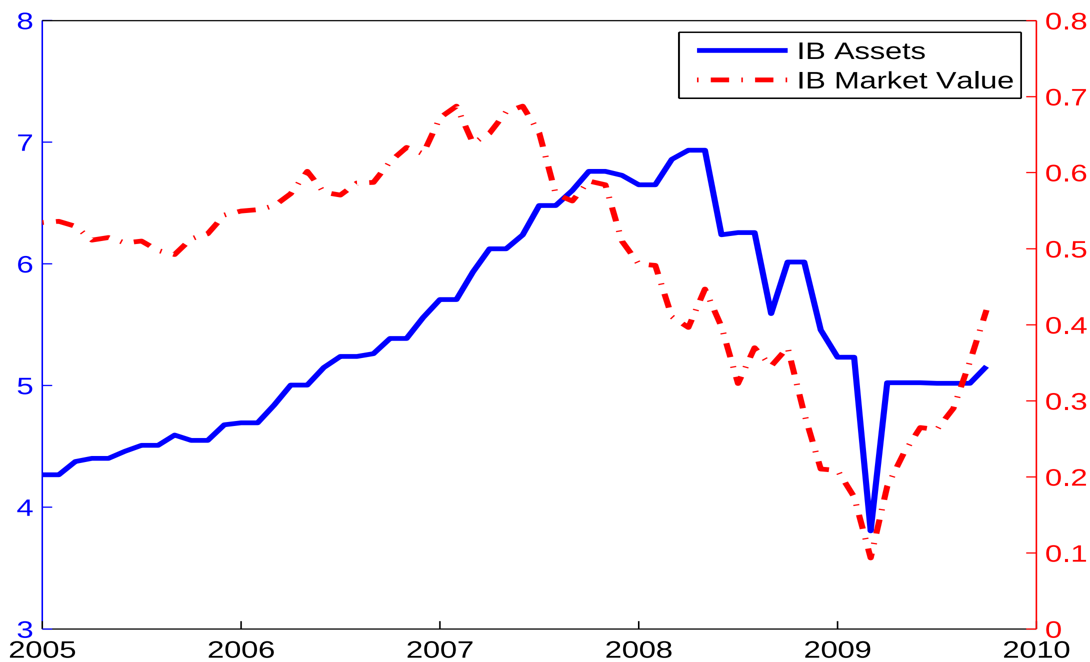
We compare average gross hedge fund leverage with the leverage of banks, investment banks, and the finance sector. The left-hand axis corresponds to average gross hedge fund leverage and the right-hand axis corresponds to the leverage of banks, investment banks, and the finance sector. The hedge fund leverage ratios consist of all observed hedge fund leverage and estimated hedge fund leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund-fixed effects. The finance sector leverage is constructing following the method described in Appendix B. The data sample is from December 2004 to October 2009.

Figure 8: Hedge Fund and Investment Bank Gross Exposure and Leverage

Hedge Funds



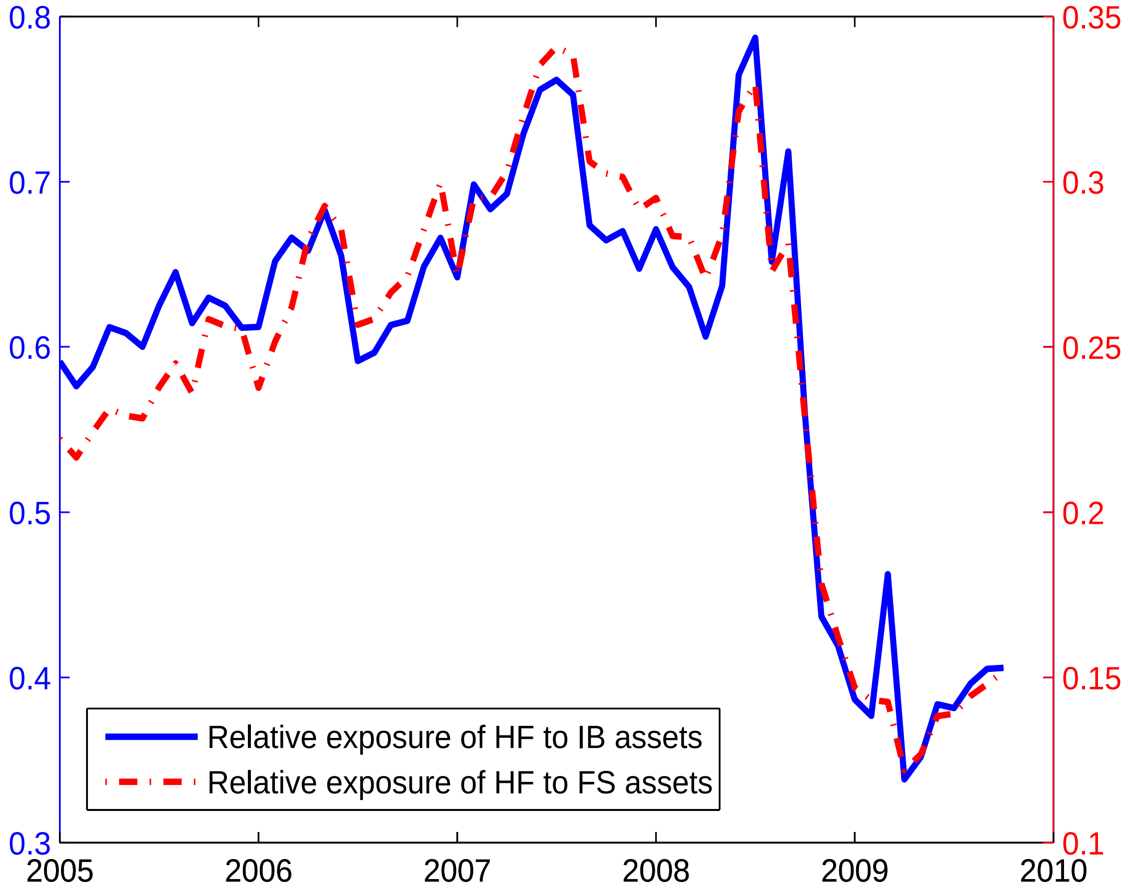
Investment Banks



Note to Figure 8

We graph the gross exposure and AUM of hedge funds in Panel A and the gross exposure and market value of equity of investment banks (IB) in Panel B. For hedge funds, we take gross leverage across all hedge funds which consists of observed gross leverage and estimated gross leverage when these are unobserved following equation (2) and the estimation method outlined in Appendix D using all macro and fund-specific variables and fund fixed effects. The hedge fund exposure is computed by multiplying the gross leverage by the aggregated AUM of hedge funds from the Barclays Hedge database. Investment bank exposure is the total amount of assets held by investment banks. The left-hand axes in both panels correspond to AUM or equity. The market value of investment banks is the value of common equity. Appendix B contains further details on these variables. The right-hand axes correspond to gross exposure. The scale of both axes is in trillions of dollars. The data sample is from December 2004 to October 2009.

Figure 9: Relative Gross Exposures of Hedge Funds to Investment Banks and the Finance Sector



We plot the ratio of gross exposure of hedge funds (HF) to investment banks (IB) and the finance sector (FS). The gross exposure is computed by multiplying gross leverage and AUM in the case of hedge funds and is total assets in the case of investment banks and the finance sector. For hedge funds, we take gross leverage across all hedge funds which consists of observed gross leverage and estimated gross leverage when these are unobserved following the estimation method outlined in Appendix D using all macro and fund-specific variables and fund fixed effects. The left-hand axis corresponds to the relative gross exposure of hedge funds to the assets of investment banks, while the right-hand axis corresponds to the relative exposure of hedge funds to the assets of the finance sector. The data sample is from December 2004 to October 2009.