Risk and Return in Convertible Arbitrage Strategies: Evidence from the Convertible Bond Market and Hedge Funds

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Risk and Return in Convertible Arbitrage: Evidence from Convertible Bond Market

Abstract

This paper analyzes the risk and return characteristics of convertible arbitrage strategy by examining the different trading strategies used by hedge funds in the convertible bond market. Majority of convertible bonds do not transact in publicly organized markets. Consequently, there is no direct way of observing the strategies employed by financial intermediaries in this market. The last decade has witnessed a continuous migration of this intermediary function from the investment banking community to the hedge fund industry. This provides us with a rare glimpse of the risk-return characteristics of arbitrageurs managing an inventory of convertible bonds to capture the liquidity premium in a manner similar to that of market makers in an over-the-counter market. We hypothesize that there are three primitive trading strategies that explain convertible arbitrage funds' returns – positive carry, volatility arbitrage, and credit arbitrage. Using data on Japanese and US convertible bonds, we create asset-based style ("ABS") factors that capture the characteristics of these primitive trading strategies. Our empirical analysis shows that these ABS factors explain a significant proportion of the return variation of convertible arbitrage hedge funds. Our empirical findings are consistent with a model where convertible arbitrage hedge funds, like market makers to the convertible bond market, have persistent net long inventory positions. Adjusting for the risk of carrying inventory, our results show that the profitability of providing financial intermediation to the convertible bond market is affected by extra-ordinary market events, the supply of bonds and the supply of risk capital to the arbitrage community. Mismatches between the supply of convertible bonds and the flow of risk capital to the arbitrageurs are shown to be a source of dislocation to the convertible bond market. Our findings lend insight to a new approach in modeling financial intermediation in hard to observe Over-The-Counter (OTC) markets.

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At the turn of the century, capitalization of the global convertible securities market was estimated at just under $300 billion.[1] Despite a number of negative market events—such as the burst of the Internet bubble, Nine-Eleven, the scandals at Enron and Worldcom—between 2000 and 2002, our data indicates that close to $300 billion of new CBs denominated in USD and Japanese Yen have been issued. This is a significant rate of growth and underscores the importance of the CB market as a source of capital under difficult market conditions. In contrast, over the same period, the US equity market, which is well over 50 times the size of the CB market, only raised about the same amount of capital in new shares issues.[2] This begs the interesting question as to who are the suppliers of liquidity to the CB market during these difficult times. In order to explore this question, we need to gain insight into the microstructure of the CB market.

However, as majority of the trading activities in the convertible bond market takes place over-the-counter (OTC), there is no direct way of observing the risk and return characteristics of providing short-term liquidity to the CB market. Fortunately, the last decade has witnessed a rapid growth in a particular group of arbitrageurs whose strategy exhibits much of the characteristics of market makers to the CB market—CA hedge funds.

Recent research points to hedge funds being the major liquidity providers to both buyers and sellers of convertible bonds; see for example, Woodson (2002), Lhabitant (2002), and Bhattacharya (2000). Estimated number of convertible arbitrage ("CA") hedge funds grew from

[1]With the United States having the largest share of the market (about 38%) followed closely by Japan (about 31%). Source: http://www.gabelli.com/news/ahw_102299.html.

[2] This data is from Federal Reserve Bulletion (various issues). We thank Jeff Wurgler for making it available on his website http://pages.stern.nyu.edu/~jwurgler/ .

less than 50 in 1995, to over 120 by the end of 2000; see Brown (2000). At the turn of the century, collectively CA hedge funds manage just under $30 billion of assets—approximately 10% of the estimated market value of the global convertible securities market. By the end of 2002, during a difficult period punctuated by negative market events, CA hedge funds attracted another $30 billion of assets under management ("AUM")—growing at an even faster rate than the underlying CB market despite difficult market conditions. As CA hedge funds typically manage their capital on a leveraged basis; a natural question that arises is what happens when the supply of liquidity to the CB market from CA hedge fund investors exceeds the needs of CB issuers? Hedge funds are not known to be long-term holders of securities, therefore if performance of CA hedge funds decline as a result of excessive capital, investors are likely to withdraw—how would this affect the CB market?

Typically, CA hedge funds are net long of CBs and employ a variety of hedging strategies to manage their CB portfolio in order to capture the liquidity premium for absorbing imbalances between the supply and demand of CBs. In this setting, CA hedge funds act like an extension to conventional market makers in the CB market placing their capital at risk to provide liquidity to CB issuers and investors, albeit selectively.[3] Therefore, not only do CA hedge funds play an important role as indirect market makers to the CB market, they also offer us a rare glimpse to the risk return characteristics of this form of financial intermediation in an OTC market.

[3] Prior literature has provided different rationales for firms issuing convertible bonds. These include mitigating the asset-substitution and underinvestment problem (Jensen and Meckling, 1976; Green, 1984), resolving the disagreement between managers and debtholders regarding estimating the risk of a firm's activities (Brennan and Kraus, 1987; Brennan and Schwartz, 1988), providing an alternative way of equity financing when conventional equity issuance is difficult due to asymmetric information (Constantinides and Grundy, 1989; Stein, 1992), and reducing the issuance costs of sequential financing to support firm's long-term strategic investments and mitigating the overinvestment problem at the same time (Mayers, 1998). As such, the quantity of issuance is likely to be affected by business needs exogenous to the CB market. We abstract from studying the motives for issuing convertible bonds in this paper and take the supply of CB as an exogenous variable to our model.

Unlike market makers in publicly traded securities, CA hedge funds are not mandated to absorb inventory at a given price. Therefore, their exposure to adverse selection risk is less than that of conventional market makers. Nonetheless, during extreme liquidity events, they too will exhibit return characteristics similar to the risk of adverse selection.

Fortunately, the last decade provides fertile grounds for observing different liquidity events in the CB market. First, the LTCM episode offers a unique glimpse on the impact on CA hedge funds during a systemic liquidity squeeze in the market place.

Second, the extant literature has shown that hedge fund returns are adversely affected by money flows chasing past performance (for example, see Agarwal, Daniel, and Naik (2005), Getmansky (2004), and Goetzmann, Ingersoll, and Ross (2003). If the *supply* of convertible bond—new issuance—is interrupted while capital flowing into CA hedge fund continues to grow based on prior performance, diminishing returns are likely to follow. In this paper, we extend the academic literature by introducing these demand-supply effects in a multifactor model and provide collaborative evidence on how they affect the risk-adjusted performance of CA strategy. Our results shed light on the recent disastrous performance of CA hedge funds—the worst performance period in over a decade.

Third, subsequent to the run of bad returns, CA hedge funds experienced a major exodus from their investors—losing nearly 20% of their AUM in the first half of 2005 alone.[4] By tracking the performance of and capital flow into convertible mutual funds during this unprecedented set of events in the CA hedge fund sector, we are able to report empirical evidence that lend insight to the questions whether CA hedge funds destabilize the CB market.

[4] Soure: Hedge Fund Research, Q2, 2005 Industry Report.

The paper is organized as follows. Section I outlines the models of CA strategies used by CA hedge funds. Section II describes the data. Section III provides a description of our empirical methodology. Section IV reviews our findings and Section V concludes the paper.

I. Models of Convertible Arbitrage Strategies

It is widely accepted that hedge funds employ dynamic trading strategies with non-linear option-like returns that cannot be captured by standard linear factor models as in Sharpe (1992).[5] For some hedge fund strategies, researchers have directly modeled the non-linear relationship between hedge fund returns and conventional asset markets in which hedge funds operate. For example, Fung and Hsieh (2001) study the risks of trend-followers using lookback options on publicly traded stocks, bonds and commodity markets to capture the path-dependent, long-gamma orientation of trend-following strategies. Mitchell and Pulvino (2001) use naked put options on equity index to mimic the deal risk inherent in diversified portfolios of announced mergers of publicly traded companies. More recently, Duarte, Longstaff, and Yu (2005) use a similar approach to study the risk and return characteristics of fixed income arbitrage hedge funds.[6]

Our model of CA hedge fund strategies is in the spirit of this stream of research. The nonlinear technology used in this study follows the approach of Fung and Hsieh (2001, 2002b). The idea is to construct Asset-Based Style ("ABS" for short) factors that would capture the return characteristics of CA hedge funds adjusting for transaction costs. An ABS factor is a

[5] See Fung and Hsieh (1997) and Agarwal and Naik (2004).

[6] Other researchers have also used alternative combinations (long-short and nonlinear combinations as opposed to conventional long-only) of conventional asset-class benchmarks to study the risks of different hedge fund strategies. These include Gatev, Goetzmann, and Rouwenhorst (1999) who investigate the risks of pairs trading strategy and Fung and Hsieh (2002a, 2004b) who study the risks of fixed-income and equity long/short hedge funds using nonlinear combinations of the underlying assets.

portfolio of conventional assets defined by a simplified proxy of a particular class of hedge fund strategies or style. Such a factor captures the strategy's essence and provides an intuitive explanation of the risks associated with otherwise opaque hedge fund strategies—Fung and Hsieh (2001) referred to these as primitive trading strategies.

The modeling process begins with identifying the risk characteristics of the underlying asset markets and the ways these risks can be managed. For convertible arbitrage, the key asset market is the convertible bond market. Conventional convertible bond valuation models focus on three sources of risks: equity risk, credit (default) risk, and interest rate risk.[7] A CA, on the other hand, is less concerned with the absolute valuation of a CB but seeks to neutralize that part of a CB's risks that is perceived to be fairly priced leaving himself to exploit other parts of the CB's return profile where the CA perceives to have a comparative advantage in managing.

A convertible arbitrage strategy ("CAS" for short) typically involves buying a portfolio of convertible securities and hedging the attendant equity risk by short-selling the underlying stock. The amount of stocks sold short is a function of the conversion ratio, the delta of the embedded call option, and the sensitivity of delta to changes in stock price, i.e., gamma. In addition to hedging equity risk, some fund managers may also hedge (in part or fully) other risks of a CB such as credit risk, interest rate risk, and volatility risk. The concept of a CAS is founded on the premise that CA hedge fund managers perceived of a comparative advantage in their ability to manage one or more of the component risks inherent in a CB. We loosely refer to

[7]See for example Brennan and Schwartz, 1977; Ingersoll, 1977; Brennan and Schwartz, 1980; McConnell and Schwartz, 1986; Buchan, 1997; Tsiveriotis and Fernandes, 1998; Davis and Lischka, 1999; and Das and Sundaram, 2004. Brennan and Schwartz (1980), Ingersoll (1977), and Brennan and Schwartz (1977) also consider the optimal call strategies for convertible bonds. It is not obvious that call risk (redemption by the issuer) is a significant risk to CAs. First, CB prices already reflect the likelihood of redemption (e.g., by trading at parity less the accrued interest). Second, there are also behavior aspects by market agents that are hard to quantify. For instance, Woodson (2002, p.28) notes that convertible issuers in Japan usually do not call their bonds to avoid upsetting their investors. Although this practice may be suboptimal with respect to short-term shareholder wealth maximization, it does mean that convertible arbitrageurs are only subject to a limited amount of call risk in practice.

such a perception as a form of relative mispricing in the sense that we do not distinguish between situations where a CB may be undervalued in general versus the arbitrageur's ability to exploit superior technology in managing CB risk and thereby extract value.[8] While potential mispricing of a CB may arise from a myriad of sources, in general they manifest themselves in how the key risk factors of a CB are priced. In other words, if market friction is such that a CB becomes mispriced, it is likely that mispricing will manifest itself in one or more of the three key components—the implied interest rate, the implied credit spread, and the implied option price. It is for these reasons that we focus on three primitive trading strategies in CA—positive carry, credit arbitrage, and volatility arbitrage. We label these as CASi, CASc, and CASv respectively.

The positive carry strategy, CASi, is designed to create a delta-neutral portfolio with positive interest income comprising a long position in the CB while minimizing equity and credit risk. The credit arbitrage strategy, CASc, is designed to create a long credit spread position while minimizing interest rate risk and equity risk. It is designed to capture value from over/under priced credit risk inherent in the CBs. The volatility arbitrage strategy, CASv, seeks to exploit underpricing in the embedded option in CBs by actively managing a delta-neutral, but long gamma, position in the underlying equity whilst minimizing interest rate risk and credit risk.

All three primitive trading strategies are variations on the basic theme that convertible arbitrageurs are essentially short-term providers of liquidity to an illiquid, incomplete CB market. In doing so, convertible arbitrageurs seek to capture a liquidity premium utilizing the CASs to manage an inventory of CBs and indirectly acting as market makers to issuers of CBs.

[8] Lhabitant (2002) attributes the rationale for following a CAS to the fact that CBs may be mispriced due to illiquidity, small issue size, and complexities associated with the valuation of these hybrid securities, whose characteristics keep changing over time. Here we use the term "mispriced" to encapsulate situations where "perceived" arbitrage opportunities arise. Perceived arbitrage opportunities arise where certain economic agents in the market can construct trading positions to exploit their comparative advantage in capturing "arbitrage-like" profits.

I.A. *Positive carry strategy, CASi*

CASi involves selection of bonds with positive carry on a daily basis. We then take delta-neutral position in each of these bonds for the period for which they continue to have positive carry. Delta-neutral position involves going long in selected bonds and shorting the underlying stocks (based on the delta of the embedded call option). We start by defining the term "carry" used for bond selection.

Carry = current income on delta-neutral position – financing cost on the convertible bond

$$Carry_t = \left(B_t \times cy_t\right) + \left(delta_t \times B_t \times \left(DISC_t - s - dy_t\right)\right) - \left(B_t \times DISC_t\right) \tag{1}$$

where

B_t is the value of the convertible bond using the closing price of day *t*, given by

$$B_t = \left(midprice_t + \left(\frac{1}{2} \times spread_t\right)\right) \times 0.01 \times F\,^{9} \tag{2}$$

$Midprice_t$ is the average of the bid and ask prices[10],

$Spread_t$ is the average (or maximum) of all available positive bid-ask spreads for day *t*,

F = unit face value of the bond,[11]

cy_t is the convertible bond's current yield on date *t*,

$delta_t$ is the convertible bond's delta on date *t,*

$DISC_t$ is the daily discount rate on date *t*,[12]

dy_t is the compensation to the stock lender for dividend paid on the stock, as a proportion of the bond price, B_t, and

s is the haircut spread, referring to the amount by which interest rate earned on the short position is lower than the discount rate (we set this spread as 0.005 or 50 basis points).

[9] In our data, $midprice_t$ and $spread_t$ are stated as percentages of par value (e.g., 105 means 105.0% of par value). Thus, we need to multiply by 0.01 to restate the bond value in Yen or $. We include the half-spread, $\left(\frac{1}{2} \times spread_t\right)$, to account for the transaction costs incurred in purchasing the bond.

[10] If only the bid (ask) price is available, we set $midprice_t$ equal to bid (ask) price. The bid and ask prices are full (dirty) prices, i.e., prices which incorporate accrued coupon income.

[11] F denotes the unit value (par value) of the bond. For a Yen-denominated bond, if the face value is 1 million Yen, then F = ¥ 1,000,000. Thus, B_t gives the Yen value of the bond position at the close of day *t*.

[12] We use the Japanese discount rate and the Fed Funds rate for Japanese and US bonds, respectively.

The first term of equation (1), $(B_t \times cy_t)$, represents the income from the coupon interest while the second term, $\left(delta_t \times B_t \times \left(DISC_t - s - dy_t\right)\right)$, represents interest income on the proceeds from the short-stock sale. Finally, $\left(B_t \times DISC_t\right)$ represents the financing cost of the convertible bond position. This financing cost is dynamic because the bond price, B_t changes from day to day.[13]

The condition for initiating the carry strategy is $Carry_t > 0$, which is equivalent to the condition:[14]

$$cy_t + \left(delta_t \times \left(DISC_t - s - dy_t\right)\right) - DISC_t > 0 \tag{3}$$

Equation (3) is the boundary condition for positive carry. We maintain the delta-neutral position as long as the boundary condition is not violated.

Implicit in the construction of the carry strategy is the partial mitigation of credit risk due to the daily rebalancing of the CB's delta. Consider the extreme case where a CB abruptly goes into default. It will be reasonable to expect the delta of the CB to drop rapidly to zero resulting in a gain from the short stock position. This "gamma" gain from the carry strategy will partially offset the loss in bond value. Since the interest return from the short delta position is a significant part of the carry strategy's return, CBs that qualify for carry considerations tend to have high deltas. While this may be an imperfect protection against credit risk of a CB, it is important to note the implicit credit-risk hedge inherent in the long-gamma position of carry positions. Next, we describe the computation of the returns for the positive carry strategy.

The capital required to support a *CASi* portfolio depends on both the short stock position and the convertible bond position. The value of the short stock position is,

$$SS_t = delta_t \times B_t \tag{4}$$

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[13] This implicitly adjusts for a positive spread between borrowing and lending.

[14] We obtain this condition by setting (1) to be greater than 0 and factoring out B_t from both sides of the inequality.

where $delta_t$ is computed assuming the stock pays a continuous dividend yield (see Merton, 1973).[15] SS_t represents the Yen or dollar value of the short stock position at the close of day t. Thus, the marked-to-market value of the portfolio with long position in bond and short position in the stock for day t is given by,

$$V_t = B_t - SS_t \tag{5}$$

For simplicity, we assume that the hedge fund manager collateralizes the trade by paying for the bond and use the bond value as collateral for the short stock position. Since the size of the carry portfolio varies daily with changing market conditions, so would the capital required to maintain the strategy.

Here we consider two alternative scenarios that can circumvent the stickiness of adjusting a fund's capital base in ensuring adequate capital support. The first scenario assumes that the manager has *perfect foresight* in terms of capital requirements and can raise capital equal to the maximum bond value during the life of the trade. In the second scenario, the manager uses only the minimum required capital to support the *CASi*—or that idle capital is zero. We provide details of computing the returns of the *CASi* under these two scenarios of capital requirements in Appendix A—labeled as Carry1 and Carry2 respectively. Subsequent empirical work shows that the overall conclusions are insensitive to the choice of Carry1 or Carry2 returns, for simplicity we therefore focus our discussion using only Carry1.[16] Next we turn to second ABS factor, credit arbitrage factor, CASc.

I.B. Credit arbitrage strategy, CASc

The credit arbitrage strategy is designed to capture value from the perceiving mispricing of credit risk inherent in CBs. We conjecture that the mispricing of credit risk is more likely to

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[15] The volatility estimate used in computing $delta_t$ is the historical volatility estimated over the past 30 trading days.
[16] Results using Carry2 are available from the authors upon request.

show up for out-of-the-money (OTM) CBs. We define OTM CBs as those bonds with parity equal to or less than 20% of par value.[17] On a daily basis, we form an equally-weighted portfolio of bonds having parity values equal to or less than 20% of par (henceforth the "credit bond portfolio"). This portfolio is rebalanced daily to retain the same basic characteristic with respect to moneyness.

In computing the daily parity of a bond, we adjust the underlying stock price for the effect of dividends. The adjustment is based on Merton (1973) and basically reduces the stock price by the present value of the stock's expected dividends. Merton's formula uses a continuous dividend yield. To estimate such a yield, we take the time series average of the underlying stock's daily dividend yield and convert the average into a continuous dividend yield. Thus, the parity value of a bond is computed as:

$$\text{Parity (conversion value) as a \% of par} = \left(\frac{\text{conversion ratio} \times S_{t-1} \times \exp(-d \times t)}{\text{par value}} \right) \times 100 \quad (6)$$

where conversion ratio is the number of shares into which the bond can be converted, S_{t-1} is the previous day's closing price for the underlying stock, d is our estimate of the continuous dividend yield (stated on an annual basis), t is the time to maturity of the convertible bond (in years) and *par value* is the convertible bond's face value. For each bond, we have a single estimate of d. If the conversion ratio and par value remain constant during our sample period, then parity will change due to (a) a shortening of the bond's time to maturity, and (b) changes in the underlying stock price. As the underlying (dividend-adjusted) stock price increases, the bond's conversion option becomes more valuable and parity increases.

Since each convertible bond is associated with an underlying stock, the formation of the bond portfolio in turn determines an equally-weighted portfolio of underlying stocks

[17] Parity is simply the market value of the shares obtained if we convert the bond immediately.

representing the portfolio's equity content. Since the CASc is designed to minimize both equity risk and interest rate risk, we need to identify proxies for both equity and interest rate risks. As a proxy for the equity risk, we use the daily returns of an equally-weighted portfolio of the underlying stocks mimicking the equity content of the CASc portfolio. To proxy interest rate risk, we use the daily returns of the Japanese 3-5 year Government Bond index from Datastream (in case of Japan) and the 5-year (constant maturity) U.S. Treasury bond yield from the Federal Reserve website (in case of the US).

The respective hedge ratios are estimated empirical via the following model:

$$BRET_t^c = \gamma_0 + \gamma_1 EQ_t + \gamma_2 IR_t + \eta_t \tag{7}$$

where $BRET_t^c$ is the day t return on the credit bond portfolio, EQ_t is the day t return on the equally-weighted portfolio of underlying stocks, IR_t is the interest rate proxy, and η_t is the random error term.[18] Please note that unlike credit arbitrage strategy, the positive carry strategy does not aim to explicitly minimize interest rate risk as it involves holding a delta-neutral position (thus minimizing equity risk) in CBs selected on the basis of their having positive carry, regardless of the level of interest rate risk embedded in them.

To summarize the CASc portfolio is *long* the equally-weighted portfolio of *CBs*, *short* the equally-weighted portfolio of underlying *stocks*, and *short* the default-free *(government) bonds*. The short positions in stocks and bonds serve to hedge against equity and interest rate risks. The hedge ratios for the stocks and bonds are $\hat{\gamma}_1$, and $\hat{\gamma}_2$ respectively.

[18] In estimating (7), we employ Newey-West standard errors to determine p-values. The Newey-West standard errors are estimated by setting the lag length to 10. The sample correlograms of the OLS residuals suggest that autocorrelations are not significant after 10 lags. For robustness, we also estimate a variant of (7) which includes the squared of the interest rate proxy. For this alternative regression specification, the coefficient for the squared term is statistically and economically *insignificant* (in both the Japanese and US cases). Furthermore, adding the squared term does not improve the regression adjusted R^2. Thus, we exclude the squared interest rate term.

In computing CASc returns we account for the financing of the convertible bonds and the rebate on the short stock and default-free bond positions in the same way as in the case of the Carry portfolio returns. The financing cost to be the discount rate, $DISC_t$, and we set the short rebate rate to be the discount rate less a spread, *s*. In other words, short positions earn an interest of $DISC_t - s$. The day *t* return on credit arbitrage portfolio is computed as:

$$CAS_{ct} = BRET_t^c - DISC_t - \hat{\gamma}_1 XEQ_t - \hat{\gamma}_2 XIR_t \tag{8}$$

where CAS_{ct} is the credit arbitrage ABS factor on day *t*, $BRET_t^c$ is the day *t* return on the credit bond portfolio, $XEQ_t = EQ_t - (DISC_t - s)$ is the difference between the day *t* return on the equally-weighted stock portfolio and the short rebate, and $XIR_t = IR_t - (DISC_t - s)$ is the difference between the day *t* return on government bonds and the short rebate, s is the spread, which we set to 0.005.

I.C. Volatility arbitrage strategy, CASv

The construction of the volatility arbitrage portfolio (CASv), follows a similar process as the other two ABS factors but for one key difference. Volatility arbitrage requires CBs with sizeable gammas. A CBs gamma peaks when its equity option component is at-the-money (ATM) [see Woodson (2002, p.130) and Calamos (2003, Chapter 5)]. Hence, we construct an equally-weighted bond portfolio for CASv (henceforth "gamma bond portfolio") comprising of CBs with parities ranging between 90% and 110% of their par values.

The main difference between CASc and CASv is that the latter hedges against credit risk, in addition to equity and interest rate risks. We begin by estimating the hedge ratios for CASv via the following OLS regression:

$$BRET_t^v = \gamma_0 + \gamma_1 EQ_t + \gamma_2 IR_t + \gamma_3 CR_t + \eta_t \tag{9}$$

where $BRET_t^v$ is the day *t* return on the gamma bond portfolio, EQ_t is the day *t* return on the equally-weighted portfolio of the corresponding underlying stocks to the gamma bond portfolio, IR_t is the Japanese 3-5 year Government Bond total return index from Datastream (in case of Japan), and the 5-year (constant maturity) U.S. Treasury bond yield from Federal Reserve website (in case of the US), CR_t is proxy for credit risk, measured as the daily change in the spread between the Japanese corporate bond yield and the Japanese long term government bond yield from Datastream (in case of Japan), and the daily change in the spread between the BAA corporate bond yield and the 10-year (constant maturity) U.S. Treasury bond yield from Federal Reserve website (in case of US), and η_t is the random error term.[19]

The resultant CASv portfolio is *long* the equally-weighted portfolio of *CBs*, *short* the equally-weighted portfolio of *underlying stocks*, *short* default-free *(government) bonds*, and *short* the *spread between corporate and government bonds*. The short positions serve to hedge against equity, interest rate, and credit risks.

In computing CASv returns, the treatment of the financing of the CBs and the rebate on the short positions are done in a consistent manner to the other strategy returns. The day *t* return on volatility arbitrage portfolio is computed as:

$$CAS_{vt} = BRET_t^v - DISC_t - \hat{\gamma}_1 XEQ_t - \hat{\gamma}_2 XIR_t - \hat{\gamma}_3 XCR_t \qquad (10)$$

where CAS_{vt} is the volatility arbitrage ABS factor, on day *t*, $BRET_t^v$ is the day *t* return on the gamma bond portfolio and $XCR_t = CR_t - (DISC_t - s)$ is the difference between the day *t* return on the credit spread position and the short rebate. Other terms in equation (10) are as defined

[19] As in the case of credit arbitrage strategy, for robustness, we estimate a variant of (9) which includes the squared of the interest rate proxy and find that it does not come out statistically significant and also does not improve the explanatory power of our regression in equation (9). Thus, we exclude the squared interest rate term.

before for equation (9). $\hat{\gamma}_1, \hat{\gamma}_2$ and $\hat{\gamma}_3$ are the OLS estimates from the estimating equation (9), which can be interpreted as the "hedge ratios" for equity risk, interest rate risk, and credit risk respectively.

I. D. Exchange Rate Factor, Fxret

Since the Japanese bonds are denominated in Yen whereas most CB funds are U.S. dollar-based, we also include an exchange rate factor, *Fxret*, in case of Japanese convertible bonds. We calculate it as $\left(Spot_t / Spot_{t-1} \right) - 1$, where $Spot_t$ ($Spot_{t-1}$) is the spot exchange rate of USD per unit of JPY at the end of month *t* (*t-1*). We include *Fxret* because we adopt the perspective of the U.S. dollar-based investor and we conjecture that the CA indexes are also created with the same perspective. To a U.S. dollar-based investor, fluctuations in the USD/YEN exchange rate present an additional risk, which must be accounted for.

Taken together, the CAS portfolios are variations of long CBs, short hedges positions spanning the universe of CBs sorted according to their parity with only weak selectivity conditions imposed in their constructions. This is done by design to reflect the role of these CAS portfolios is one of inventory risk management not as trading tools to identify mispriced bonds in the secondary market. In fact, we provide evidence that adjusting for these inventory management risks, there is a positive association between CA profits and new issues of CBs.

II. Data

Our sample consists of daily closing prices of the convertible bonds and their underlying stocks for 830 Japanese and 2,243 US convertible bonds.[20] We also obtain contractual information of each bond including the conversion price, maturity date, call provision, and

[20] All Japanese bonds are denominated in Japanese Yen. Hence, we include an exchange rate factor for Japanese convertible bonds. We describe the construction of this factor later in the paper.

dividend yield on the underlying stock. Table I provides descriptive statistics of our sample of Japanese convertible bonds. In Panel A of Table I, we observe that the number of issuers decreases as the number of issues per issuer increases. This suggests that there are more firms selling a single issue of convertible bonds than there are firms selling multiple issues of bonds. In total, there are 590 Japanese firms with 830 separate issues of convertible bonds, and 1,897 US firms with 2,243 separate convertible bond issues.

In Panel B of Table I, we provide summary statistics on issue size. The average CB issue is $202 million (23 billion Yen) in case of Japan and $300 million in case of US.[21] The median issue size is $105 million (12 billion Yen) for Japanese CBs and $170 million for US CBs. Hence, the mean and median issue sizes in Japan and US are of similar order of magnitude.

Panel C of Table I tracks the growth of the number of bonds in the sample. This panel shows that while there are 830 Japanese and 2,243 US bonds over the entire sample period, the number of bonds vary throughout the sample period. At the end of 1993 (first year of the sample), there are 27 Japanese and 10 US bonds. The number of bonds increased dramatically in 1995. At the end of 1995, there are 212 Japanese and 45 US bonds in our sample. We observe an even more dramatic growth in the case of US convertible issues between December 1997 and December 1998, when the number of bonds increases almost threefold from 152 to 430. The size of our Japanese bond sample reaches a high of 668 at the end of 2001. Thereafter, the number of Japanese convertibles declines to 245 at the end of 2002. In contrast, our US bond sample continues to grow after 1998, ending with 1,037 bonds at the end of 2002.

Next, we describe the characteristics of the ABS factors in Table II. We start with the Japanese ABS factors. Panel A of Table II shows that, on average, the positive carry portfolio

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[21] To convert the Japanese bond issue sizes from Yen to US dollars, we use the time series average of daily Yen/USD exchange rates between January 1991 and April 2003 (113.81 Yen/ 1 USD). We obtain the exchange rate series from the Federal Reserve.

has about 10 times as many bonds as the gamma and credit bond portfolios (207 versus 26 and 28). This suggests that during our sample period, the positive carry strategy is applicable for a larger number of bonds compared to the credit arbitrage and volatility arbitrage strategies. The carry and credit portfolios have higher current yields than the gamma portfolio. This is not surprising as carry is positively related to current yield [see equation (1)] while for the credit portfolio, the current yield is high because of the low bond prices associated with out-of-the-money convertible bonds. The average parity for the gamma (credit) portfolio is 98% (10.8%). These figures are consistent with our bond selection criteria. For the U.S. ABS factors, we observe similar patterns. Panel B of Table II shows the average number of bonds used in constructing each ABS factor for each year during our sample period. The averages increase significantly across all factors during the latter half of our sample period (1998-2002), a reflection of the increase in our bond sample during the same period (see Table I Panel C).

Finally, in Table III, we provide the descriptive statistics of our ABS factors and the four convertible arbitrage indexes (from CISDM, HFR, MSCI, and TASS) over the period January 1993 to April 2003. Agarwal, Daniel, and Naik (2005) document there is little overlap between these major hedge fund databases. Hence, to obtain a more representative sample of CA funds, we also construct an equally-weighted portfolio of all CA funds in our hedge fund sample and report all our results for this portfolio (EW). For robustness, we also conduct our analysis with a value-weighted portfolio of all CA funds and find similar results.[22]

We start with the description of the Japanese ABS factors. CASv has the highest average monthly return followed by the CASi and CASc. CASi and CASc are more volatile than CASv. For the US ABS factors, we observe CASi having a higher average monthly return than the other

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[22] These are available from the authors upon request.

two ABS factors.[23] The standard deviations of CASi and CASc are roughly twice as large as that of CASv.

The convertible arbitrage indexes have very similar average monthly returns of around 1%. These indexes, in general, have lower volatility than individual ABS factors. This makes sense as CB funds may be diversifying their risk by investing in multiple strategies across different markets.

Table III also displays the correlation matrix of the ABS factors, the four convertible arbitrage indexes, and our equally-weighted portfolio of all CA funds. We first examine the correlations among the Japanese ABS factors. CASc is significantly correlated with CASi and CASv but the magnitudes of the correlations are not large. The US ABS factors are also largely uncorrelated with each other. Furthermore, the US and Japanese factors are generally uncorrelated. The only significant correlations are those between US and Japanese carry, US and Japanese credit and US credit and Japanese gamma. In these cases, the magnitudes are again not large. Based on these correlation figures, one can easily infer that there is no concern of multicollinearity in using these ABS factors together as explanatory variables in our regressions later on. Turning to the convertible arbitrage indices, as expected, we find that they are highly correlated with each other. The correlation coefficients range from 0.75 to 0.93 and are all significant at the 1% level. Having described our data, we next examine how well our three ABS factors explain the returns of the convertible arbitrage strategy.

III. Empirical Methodology

A. In-Sample Analysis of Risk-Return Characteristics of CA Strategies

[23] Interestingly, the average monthly returns of volatility arbitrage strategies in the US and Japan are comparable to those documented in Duarte, Longstaff, and Yu (2005) for the fixed income volatility arbitrage strategy.

A1. Adjusting for the inventory effect on CA hedge fund returns

In our model, the demand side of the CB market is proxied by two distinct groups of bond holders—the long-term holders of CBs proxied by CB mutual funds and market makers proxied by CA hedge funds. To model CA hedge funds' ability to mitigate inventory management risk, we need a specification that allows for hedge fund managers to fall somewhere between a passive holder of CB inventory and that of a pure CA hedge fund. We accomplish this by conducting our analysis in two steps. First, we filter out that part of CA hedge fund's returns that are akin to holding a passive inventory of CBs—mutual-fund-like returns. Then we model the residual part of CA hedge fund returns via our CAS portfolios in a separate step. Specifically, in step 1 of our model we perform the following analysis:

$$CA_t - r_{f,t} = \gamma_0 + \gamma_1(VG_t - r_{f,t}) + \eta_t \qquad (11)$$

where CA_t is the month t return on a portfolio or index, $r_{f,t}$ is the risk free rate which we proxy with the US Fed Fund rate for month t, VG_t is the month t return on the Vanguard Convertible Securities mutual fund, and η_t is the month t residual return from the regression. Next we need to model the residual returns, η_t.

A2. Adjusting for changing financial market conditions

The challenge here is to specify an econometric model of the various CA strategies that captures both market practices as well as changing financial market conditions. Over the past decade, the content of the global CB market fluctuated with the dramatic changing fortunes of the Japanese CBs (see Table 1). Hedge fund managers are known for their nimbleness and ability to circumvent market barriers. It was therefore necessary for us to compute CAS portfolios encompassing opportunities in both the US and Japanese CB markets in order to properly reflect the CA hedge funds' opportunity set.[24] This meant that there are six CAS portfolios—three for the US CBs and three for the Japanese CBs.

Although the CAS portfolios are constructed from daily bond prices, CA hedge fund returns are only available on a monthly basis. This greatly limits our ability to fully specify a model of CA hedge fund returns using our CAS portfolio returns that admits stochastic betas. Here we adopt the model put forward in Fung and Hsieh (2004a) and formalized in Fung, Hsieh, Naik and Ramadori (2005). This model is predicated on sample breaks in the historical return series motivated by major market events. In our specification, we conjectured that this is indeed the case with CB hedge funds but go further to show that the event specifications are different from that of Fung, Hsieh, Naik and Ramadori (2005)[25] and are specific to CB hedge funds.

It is for these reasons that in step 2 of our analysis we apply the following model:

$$\begin{aligned}\eta_t = \alpha + \beta_1 CAS_{it}^{US} + \beta_2 CAS_{vt}^{US} + \beta_3 CAS_{ct}^{US} + \beta_4 CAS_{it}^{JP} \\ + \beta_5 CAS_{vt}^{JP} + \beta_6 CAS_{ct}^{JP} + \beta_7 Fxret_t + \varepsilon_t\end{aligned} \tag{12}$$

where the alpha and betas are defined as: $\begin{aligned}&\alpha = \alpha_0 + \alpha_1 D \\ &\beta_i = \beta_{i0} + \beta_{i1} D, \quad i = 1, 2, ..., 6\end{aligned}$

D is specified as: $D = \begin{cases} 0 & \text{if month is during 10/1998 - 8/2002} \\ 1 & \text{if month is before 10/1998} \end{cases}$

$Fxret_t$ is the exchange rate factor, and the three ABS factors are $PCAS_{it}$, $PCAS_{vt}$, and $PCAS_{ct}$.[26] α, β_1 to β_7 are the regression parameters and ε_t is the error term.

A3. Adjusting for supply and demand effect of CBs

[24] CBs denotes in Euros are not included as they are of limited size and history compared to US and Japanese CBs.
[25] Their data set is based on large portfolios of hedge funds.
[26] We denote the US and Japanese ABS factors with the superscripts *US* and *JP* on the three factors.

In our setting, CA hedge funds are suppliers of liquidity to CB market. As such, their performance must be sensitive to demand-supply factors in the convertible bond market. Anecdotal evidence from the popular press estimates that more than 75% of all convertible bonds issued are owned by hedge fund managers (Zuckerman and Sender, 2005). However, CA hedge funds deploy their capital on a leveraged basis and are likely to vary the degree of leverage in respond to market conditions. To circumvent this problem we proxy the demand for CBs from CA hedge funds as the amount of risk capital they control—this is reflected in the time series of aggregate assets under management ("AUM" for short).

To measure the supply of CBs, we simply use the market capitalization of the outstanding convertible bonds in the Japanese and the US markets with one additional adjustment.[27] We need to account for the amount of CBs owned by long-only investors such as convertible bond mutual funds and other long-biased investors such as fixed income convertible bond (FICB) hedge funds. Hedge Fund Research (HFR) defines the FICB strategy as "…primarily long only convertible bonds".[28] The supply of convertible bonds is adjusted accordingly by subtracting the total assets under management for convertible bond mutual funds and FICB hedge funds from the total market capitalization of convertible bonds. Finally we aggregate the US and Japanese series into a single time series of issuance encompassing both markets.

To illustrate how the supply and demand in the convertible bond market vary over time, we plot the total AUM of CA funds and long-biased convertible funds along with the total market capitalization of convertible bonds in the US and Japan together in Figure 1. Superficially, it appears that the supply of convertible bonds is much higher than the demand for these bonds.

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[27] For the Japanese market, bond prices are in Yen, so we convert them to US dollars using a monthly Yen/USD exchange rate.
[28] Source: http://www.hedgefundresearch.com/index.php?fuse=indices-str#2282

However, CA hedge funds are leveraged holders of CBs. Therefore their aggregate AUM only reflects the lower bound of the quantity of CBs in their portfolios.

It is interesting to observe the similarity in the trend of the total market capitalization of convertible bonds and the aggregate AUM of CA hedge funds.[29] Clearly, risk-adjusted performance is the link between CA hedge fund investors' capital flow and the supply of CBs. To integrate this effect into modeling of CA hedge fund returns, we introduced a new variable to our econometric model—the ratio of supply to demand, *mktaum,* to capture changing supply and demand conditions in the CB market. The numerator is the market capitalization (cap) of all US and Japanese convertibles where the market cap of Japanese convertibles is expressed in US dollars, minus the total assets under management (AUM) for convertible bond mutual funds and FICB hedge funds. The AUM data for the convertible bond mutual funds is from the CRSP mutual fund data base (those with Strategic Insight (SI) objective as "CVR") and the FICB hedge funds data is from the HFR database. The denominator is the total asset under management (AUM) of all convertible funds in our sample.[30]

Introducing the supply-demand effect modifies equation (12) adding six more variables:

$$\begin{aligned}\eta_t = \alpha + \beta_1 CAS_{it}^{US} + \beta_2 CAS_{vt}^{US} + \beta_3 CAS_{ct}^{US} + \beta_4 CAS_{it}^{JP} \\ + \beta_5 CAS_{vt}^{JP} + \beta_6 CAS_{ct}^{JP} + \beta_7 Fxret_t + \varepsilon_t\end{aligned} \tag{13}$$

where the alpha and betas are defined as: $$\begin{aligned}\alpha &= \alpha_0 + \alpha_1 D + \alpha_2 mktaum_{t-1} \\ \beta_i &= \beta_{i0} + \beta_{i1} D + \beta_{i2} mktaum_{t-1}, \qquad i = 1, 2, ..., 6\end{aligned}$$

D is specified as: $D = \begin{cases} 0 & \text{if month is during 10/1998 - 8/2002} \\ 1 & \text{if month is before 10/1998} \end{cases}$

[29] In contrast, the growth in the AUM of the long-biased convertible funds is not as spectacular.

[30] For robustness, we also use the AUM of only the convertible bonds that are selected for executing the primitive trading strategies, (i.e., constructing our various ABS factors) as the denominator for the *mktaum* variable. Our results remain unchanged using this alternative measure.

and $mktaum_{t-1}$ is lagged value of market cap to AUM ratio. The other variables are as in equation (12).

B. Event Analysis of the CB market

B1. Supply side shocks

To observe the time variation in the pattern of CB supply, we plot the time series of new CB issuance between Jan 1993 and Apr 2003 in Figure 2. In order to examine if our issuance data represents the supply of CBs well, we also plot in Figure 2 the time series of issuance data from an alternative source, Securities Data Company (SDC), which is widely used by academics for research on new issues. Figure 2 shows that we capture more issuance data than that in the SDC database and the striking resemblance in the issuance trends confirms that our sample is representative of the issuance during this period. New issuance of CBs reached a low point during the LTCM crisis. It recovered thereafter reaching a peak during the early part of 2001 and declined steadily during 2002 in the midst of the Enron and Worldcom scandals. New issuance of CBs resumed towards the end of 2002 but started to decline steadily from the summer of 2003 and remained low throughout 2004 and 2005. Given the different nature of the three low points in CB supply, we chose to analyze these events separately. The sample-break model in equation (13) is used to cover the period January 1993 to August 2002. This allows us to study the combined effect of a hedge fund event like LTCM and a low point of CB supply around that time. In addition, it also allows us to compare the LTCM event to the end of the Internet bubble where the supply of CBs continued uninterrupted.

To extend the above model to the next event point at August 2003 would have meant adding too many new dummy variables with only 12 more monthly observations of returns. This will seriously jeopardize the interpretation of the statistical results. We therefore, adopted a different approach. To test whether our model captures the effect of the precipitous drop in CB supply in August 2002 and the subsequent recovery, we employ an out-of-sample analysis for this period.

Specifically, we use the estimated regression model to predict the monthly residual returns of the CA hedge funds between September 2002 and April 2003. This is summarized in a univariate regression of actual returns on predicted returns.

$$\eta_{it} = \alpha_i + \beta_i \hat{\eta}_{it} + u_{it} \tag{14}$$

where η_{it} is the actual return in month *t*, and $\hat{\eta}_{it}$ is the predicted return for month *t*. The R^2 from this regression provides a quantitative gauge of our model's out-of-sample performance. The choice of ending the out-of-sample analysis is dictated by the availability of CB data which, at the time of writing, ended around that time.

B2. Demand side shocks

Figure 1 recorded the almost continuous growth in the AUM of CA hedge funds throughout the past decade. Figure 2 shows that new issuance CBs stayed at the lower range of historical level since the last peak in the summer of 2003. This begs the question as to what happens under such a scenario to CA hedge fund performance and how would investors respond? To answer this question, we tabulate the performance of CA hedge funds, CB mutual funds against the flow of assets in and out of these investment vehicles. Specifically we show that CA hedge fund investors withdrew subsequent to poor performance whereas CB mutual funds were by and large unaffected.

IV. Empirical Results

The regression models use the CA indexes from four popular hedge fund databases: CISDM, HFR, MSCI, and CT as well as an equally-weighted portfolio of all CA funds in our sample (EW). From these four databases we identified 155 unique convertible arbitrage funds which existed during the period between January 1993 and April 2003. The AUM of these 155 funds are used to construct the *mktaum* variable. Figure 3 is a Venn diagram showing the distribution of these funds among the four databases. One striking feature of Figure 3 is that HFR and CT are the two major contributors of convertible arbitrage hedge funds, subsuming the contributions from CISDM and MSCI. Although there are overlaps in the coverage, a considerable number of CT funds (73 funds, or 47.10% of the total) are not found in any other databases. The same can be said for HFR, which has 30 funds (or 19.35% of the total) not available in any other databases. The Venn diagram indicates that the databases overlap but do not provide *identical* coverage. This observation foreshadows a degree of heterogeneity in the behavior of the CA indexes, a point we make in the results section.

First pass results:

- We estimate our model over the sample period of January 1993 and August 2002 and report the results in Table IV.[31] Panel A presents the results from estimating equation (11).
- Panel A indicates that the intercept, γ_0, is positive and significant for all four indexes and the equally-weighted portfolio. In each case the coefficient on VG is positive and significant for all CA indexes and the EW portfolio. However, the magnitudes of the

[31] We set aside September 2002 – April 2003 as a holdout sample for our out-of-sample analysis.

regression slopes are small ranging from 0.09 to 0.17. This is consistent with CA funds' attempt to hedge out a substantial part of the market risk. The R^2 of the CA indexes are generally low, ranging from 10.72% (CT) to 30.28% (CISDM).

- Recall from Figure 3 that the databases overlap, but do not provide identical coverage. If the CISDM universe covers a group of funds which do not match the *entire* HFR universe, then it's possible that the two indexes have dissimilar R^2's and coefficients on VG. The same argument can be extended to explain the heterogeneity across the CA indexes.
- Turning to the EW portfolio, we see that its R^2 is much higher – 35.83%. Given that the EW portfolio is constructed using funds from the four databases, one would expect the VG coefficient and explanatory power to be within the range obtained by the CA indexes. We conjecture that, within the group of CA funds, bigger funds (funds with larger AUM) may behave differently from smaller funds (funds with smaller AUM). Specifically, bigger funds may be more "arbitrage-like" whereas, smaller funds tend to be more "mutual fund-like". To investigate this possibility, we form two sub-portfolios of CA funds – "Small" and "Big". The Small portfolio consists of funds with below median AUMs as of the previous month end, while the Big portfolio consists of funds with above median AUMs as of the end of previous month. In other words, in each month, we rank the universe of CA funds into these two portfolios based on the funds' assets in the previous month. We estimate equation (11) for Small and Big and report the results in Table IV.
- Consistent with our conjecture, small funds have a higher loading on VG than big funds. In addition, VG explains about 36% of the variation in small CA fund returns, but only

27% of the variations in big CA fund returns. Note that the adjusted R^2 on big funds is comparable to that of the HFR index. This suggests that bigger CA funds are more "arbitrage" like and behave less like long only convertible portfolios. In contrast, smaller CA funds have a stronger bias towards long only convertible portfolios. This behavior can be gleaned from the bigger loading on VG and the higher adjusted R^2. One final observation is that the "market model" specification fails to explain even half of the return variations in CA returns.

Second Pass Results:

- In Panel B of Table IV, we observe that for all the indexes and our EW portfolio, the interest rate arbitrage strategy in US appears to be common primitive trading strategy as the coefficient on $PCASi^{US}$ is positive and statistically significant for all four indexes and the EW portfolio. The same can be said of the volatility arbitrage strategy in Japan. For other primitive trading strategies, we observe varying exposures for the different indexes and EW portfolio, suggesting that the heterogeneity among the CA funds included in them.
- For all indexes, we see that the interaction between *D* and ABS factors are statistically significant in a number of cases. We observe similar pattern for the equally-weighted (EW) portfolio of CA funds. This suggests that ABS factor betas respond to the September 1998 break and the evidence is present for indexes and individual funds.[32]

[32] To test the hypotheses of a structural break after the LTCM episode, one could conduct the F-test for $\alpha_1 = \beta_{11} = \beta_{21} = \ldots = \beta_{61} = 0$. Following Fung, Hsieh, Naik, and Ramadorai (2005), we conduct such a test using White's (1980) heteroskedasticity consistent covariance matrix estimator.

The Supply/Demand effect

- In addition, we find the interaction of demand-supply factor ($mktaum_{t-1}$) with the ABS factors to be statistically significant in a number of cases. This suggests that the mismatch between demand and supply of convertible bonds is an important source of profitability for CA strategy. Finally, none of the intercept terms for the indexes and EW portfolio are positive and significant. This shows that after accounting for systematic risk factors for the convertible arbitrage strategy, CA funds fail to provide any abnormal returns.[33]
- In terms of explanatory power, our model explains between 11% to 35% of the variation in the CA indexes, and 20% for the EW portfolio. Consistent with the conjecture made with respect to the step 1 analysis, we see that the bigger CA funds have an adjusted R^2 of 29% while smaller CA funds have an adjusted R^2 of about 9%. To the extent that our conditional model captures convertible arbitrage activities, the bigger CA funds seem to be more involved in arbitrage activities than smaller funds. Overall, these results suggest that our asset-based factor model, which accounts for structural breaks and mismatches between demand and supply of convertible bonds is able to explain the risk-return characteristics of convertible arbitrage strategy well.

Event Analysis

Out-of-sample tests from September 2002 to April 2003.

- Until now, we have shown how our model is able to explain the returns of convertible arbitrage strategy within our sample. To demonstrate the efficacy of our model further,

[33] Interestingly, when we split our sample of convertible bonds into new issues and seasoned issues and conduct our analysis separately for these two sub samples, we find that the intercepts from the sample of new issues tends to be larger than that for the seasoned issues. This suggests that CA funds may be profiting from the underpricing in convertible IPOs (see King, 1986; Carayannopoulos, 1996; Buchan, 1998; Carayannopoulos and Kalimpalli, 2003; Amman, Kind, and Wilde, 2004; Chan and Chen, 2004 for underpricing literature that suggests that the market prices of convertible bonds are lower than the theoretical prices from conventional valuation models).

we conduct an out-of-sample analysis. Specifically, we use the estimated regression model (reported in Table IV) to predict the monthly residual returns of the CA indexes, and the EW portfolio between September 2002 and April 2003. The choice of this out-of-sample period is driven by the fact that the convertible bond issuance almost dried up completely in both US and Japan in August 2002 (see Figure 2). By choosing out-of-sample period starting in September 2002, we want to relate the changes in the issuance trends with the recent losses faced by CA funds. It should be noted here that before August 2002, the convertible issuance had gone down to zero in August 1998 during the LTCM crisis, which we already take into account in our model through the structural break.

- We plot the monthly actual and predicted returns for the four CA indexes and the EW portfolio in Figure 4. A visual inspection of these plots indicates that the predicted returns do track the actual returns fairly closely.
- The R^2 from equation (13) provides a quantitative gauge of our model's out-of-sample performance. We report the univariate regression estimates of α_i and β_i as well as the R^2 in Table V. The R^2's from the univariate regressions range from 41% to 85% for the CA indexes and the EW portfolio. These results suggest that our model not only explains the in-sample variation in returns of convertible arbitrage, it also has substantial out-of-sample predictive ability. The out-of-sample regression reinforces the distinct characteristics of big and small CA funds. Because bigger CA funds exhibit stronger arbitrage like behavior, our conditional model does a much better job of predicting the returns of bigger funds than the returns of smaller funds. Specifically, for bigger funds, predicted residual returns explain about 44% of the actual residual returns. In contrast, for

smaller funds, predicted returns only explain about 33% of the actual returns. These comparisons are consistent with the in-sample regression analyses. We also note that, since the aggregate EW portfolio combines both big and small funds, it's not surprising that the adjusted R^2 lies between 33% and 44%.

Sensitivity Analysis

In the final part of our analysis, we ask the question "How do the ABS factors and the demand-supply factor affect convertible arbitrage returns during the sample period?" Specifically, we evaluate the change in returns given a one standard deviation change in the variable of interest, while holding all other factors constant. To calculate the change in convertible arbitrage return given a change in an ABS factor, we take the partial derivative of η_t in (12) with respect to the ABS factor. For the *i*th factor, the partial derivative is

$$\partial\eta_t / \partial ABS_i = \beta_{i0} + \beta_{i1} D + \beta_{i2} mktaum_{t-1}, \qquad i = 1, 2, ..., 6 \tag{14}$$

This implies that

$$\partial\eta_t = \left(\beta_{i0} + \beta_{i1} D + \beta_{i2} mktaum_{t-1}\right) \times \partial ABS_i \tag{15}$$

Using (15), we compute the change in convertible arbitrage return given a one standard deviation change in the *i*th ABS factor and holding $mktaum_{t-1}$ at its sample mean. We do this when $D = 1$ (sample period before the structural break) and $D = 0$ (sample period after the structural break). To assess the impact of the demand-supply factor, we take the partial derivative of (12) with respect to $mktaum_{t-1}$ holding each ABS factor at its sample mean,

$$\partial\eta_t / \partial mktaum_{t-1} = \alpha_2 + \sum_{i=1}^{6} \beta_{k2} \overline{ABS_i} \tag{16}$$

Where $\overline{ABS_i}$ is the sample mean of the *i*th ABS factor (e.g., $\overline{ABS_1} \equiv \overline{PCAS_i^{US}}$, the sample mean of the US carry factor). Equation (16) implies that

$$\partial\eta_t = \partial mktaum_{t-1} \times \left(\alpha_2 + \sum_{i=1}^{6} \beta_{i2}\overline{ABS_i}\right) \tag{17}$$

α_2 represents the influence of *mktaum$_{t-1}$* via the intercept, while $\left\{\beta_{i2}\right\}_{i=1}^{6}$ represent the influence of *mktaum$_{t-1}$* through the ABS factor exposures. Given (16), we compute the impact on convertible arbitrage returns when there is a one standard deviation change in *mktaum$_{t-1}$*. We implement (14) and (16) using the estimated regression coefficients $\widehat{\alpha_2}, \left\{\widehat{\beta_{i0}}, \widehat{\beta_{i1}}, \widehat{\beta_{i2}}\right\}_{i=1}^{6}$. The results for the Small and Big portfolios are similar to that of the aggregate EW portfolio. Thus, for brevity, we focus our discussion on the four indexes and the aggregate EW portfolio. Table VI indicates that a one standard deviation change in mktaum$_{t-1}$ generally has a positive impact on the indexes and the equally-weighted portfolio. To be precise, holding the ABS factors at their sample means and making a one standard deviation change in *mktaum$_{t-1}$* increases CISDM return by 0.12%, CT return by 0.58%, HFR return by 0.19%, MSCI return by 0.02%, and the EW return by 0.28%. The effect of *mktaum* does not vary before and after the structural break. This is to be expected, given that the partial derivative does not depend on the structural dummy, D.

Across the entire sample period, the CA funds generally profit from interest rate and credit arbitrage in US convertibles. A one standard deviation change in $CASi^{US}$ or $CASc^{US}$ has a positive impact on the return of CISDM, HFR, MSCI, and the equally-weighted portfolio before the structural break. After the break, the MSCI index continues to profit from interest rate arbitrage while funds covered by all indexes and the equally-weighted portfolio benefit from credit arbitrage. We observe that the US carry and volatility factors have a bigger positive impact on CA returns before the structural break while the credit factor tend to have a bigger positive impact after the break. For example, a one standard deviation change in $CASi^{US}$ raises MSCI return by 0.27% before the break, and 0.02% after the break. In contrast, a one standard deviation change in $CASc^{US}$ increases HFR return by 0.11% before the break, and 0.22% after the break.

Across the entire sample period, the CA funds generally profit from credit arbitrage in Japanese convertibles. With the exception of CT, a one standard deviation change in $CASc^{JP}$ has a positive impact on CA returns before and after the structural break. We observe that the JP volatility factor has a bigger positive impact on CA returns after the structural break, in contrast to their US counterparts. For example, a one standard deviation change in $CASv^{JP}$ raises HFR return by 0.13% before the break, and 0.31% after the break. A one standard deviation change in the $CASi^{JP}$ generally lowers investment performance, while one standard deviation change in $CASc^{JP}$ generally has a bigger positive impact on CA returns after the structural break. For example, a one standard deviation change in $CASc^{JP}$ raises HFR return by 0.01% before the break, and 0.25% after the break.

V. Concluding Remarks

This paper analyzes the risk-return characteristics of convertible arbitrage funds. We contribute to the extant literature by conducting an asset-based style (ABS) analysis to extract the common risk exposures of convertible arbitrage strategy followed by large number of hedge funds. For this purpose, we use high-frequency data from the underlying convertible bond and stock markets in the US and Japan. After accounting for transaction costs, we model the different primitive trading strategies used by hedge funds to construct our asset-based style factors. These factors provide important insights into the nature of risks associated with investing in convertible arbitrage hedge funds.

In particular, our results show that three primitive trading strategies – positive carry, volatility arbitrage, and credit arbitrage explain a large proportion of the return variation in convertible arbitrage hedge funds. Further, our results demonstrate that the profitability of providing financial intermediation to the convertible bond market is indeed affected by extraordinary market events such as the LTCM crisis and the mismatch between demand for and supply of convertible bonds. In addition to explaining the within-sample variation in the CA indexes, our model also demonstrates substantial out-of-sample predictive ability. To the extent that the ABS factors explain a significant faction of the return variation in convertible arbitrage funds, we believe our approach has important implications for risk management, portfolio construction, and benchmark design in the hedge fund industry.

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Table I: Descriptive statistics of Japanese and U.S. convertible bonds

This table provides the summary statistics of our sample of 830 Japanese and 2,243 U.S. convertible bonds. Panel A provides the breakdown of our sample by the number of issues per issuer. Panel B provides the summary statistics of issue size (in millions of USD). To convert the Japanese bond issue sizes from Yen to US dollars, we use the time series average of daily Yen/USD exchange rates between January 1991 and April 2003 (113.81 Yen/ 1 USD). In Panel C, each entry is the number of bonds observed at the end of the year. For example, 12/1997 refers to the number of bonds observed on the last trading day of 1997.

Panel A: Breakdown of sample by the number of issues per issuer						
	Japanese bonds			U.S. bonds		
	Number of issues per issuer	Number of issuers	Total number of bonds	Number of issues per issuer	Number of issuers	Total number of bonds
	1	426	426	1	1636	1636
	2	113	226	2	204	408
	3	33	99	3	34	102
	4	11	44	4	20	80
	5	7	35	5	2	10
				7	1	7
		590	830		1,897	2,243
Panel B: Summary statistics of issue size						
Average issue size (mil)		$ 202			$ 300	
25th percentile (mil)		$ 70			$ 100	
50th percentile (mil)		$ 105			$ 170	
75th percentile (mil)		$ 220			$ 325	
Panel C: Number of bonds during the sample period						
		Japan			US	
12/1993		27			10	
12/1994		43			11	
12/1995		212			45	
12/1996		244			60	
12/1997		252			152	
12/1998		244			430	
12/1999		468			655	
12/2000		536			698	
12/2001		668			1086	
12/2002		245			1037	

Table II: Characteristics of Portfolios generating Carry, Volatility Arbitrage, and Credit Arbitrage Asset-Based Style Factors

Panel A provides the daily average current yield, parity, and delta of the portfolios generating the CASi, CASv, and CASc Asset-Based Style (ABS) factors, where the daily average is taken across all bonds in each of the portfolios. CASi is the Carry ABS factor computed using the 'perfect foresight' capital base assumption, CASv is the ABS factor for volatility arbitrage, and CASc is the ABS factor for credit arbitrage. Current yield is computed using a full year's coupon divided by the bond's mid-price (which incorporates accrued interest). Parity is the bond's conversion value as a percentage of the par value. The start and end dates mark the start and end of the respective portfolios. Panel B gives the average number of convertibles which enter into the creation of each ABS factor. For each calendar year, we compute the number of bonds used to create each factor every month. We then take the 12-month average and report that number in Panel B.

		Japan			*U.S.*	
	CASi	CASv	CASc	CASi	CASv	CASc
Panel A: Characteristics of portfolios						
Size of portfolio	207	26	28	297	48	140
Current yield (%)	1.6	1.0	2.1	10.3	8.9	25.3
Parity (%)	65	98	10.8	68	99	9.2
Start date	2/24/1993	3/19/1993	1/4/1993	3/1/1993	12/14/1993	1/1/1993
End date	4/30/2003	4/30/2003	4/30/2003	4/30/2003	4/30/2003	4/30/2003
Panel B: Average number of bonds in each factor						
1993	22.5	2.2	5.6	9.5	1.0	2.0
1994	28.6	4.8	2.9	11.0	1.0	1.0
1995	180.1	20.9	18.3	35.1	5.1	6.7
1996	249.0	72.6	9.5	48.3	13.0	6.9
1997	298.5	43.3	19.3	57.4	16.0	16.3
1998	298.7	29.5	41.8	209.5	48.8	98.3
1999	365.2	60.9	63.6	382.3	78.5	168.8
2000	396.9	71.5	72.0	449.9	96.8	205.0
2001	524.1	95.0	94.4	574.1	107.8	380.5
2002	411.7	58.8	76.3	607.1	97.0	421.7

Table III: Descriptive Statistics of Asset-Based Style (ABS) Factors and Convertible Arbitrage Indexes

This table provides the descriptive statistics of and correlations between the monthly returns of the ABS factors (CASi, CASv, and CASc) and the monthly returns of convertible arbitrage indexes and our equally-weighted portfolio of all convertible arbitrage funds (EW) over the period 1/1993 – 4/2003. CASi is the Carry ABS factor computed using the 'perfect foresight' capital base assumption, CASv is the ABS factor for volatility arbitrage, CASc is the ABS factor for credit arbitrage, and Fxret is the exchange rate factor. CISDM, CT, HFR, and MSCI refer to the convertible arbitrage indexes from the four databases respectively, EW is the equally-weighted portfolio of convertible arbitrage (CA) funds, Small is the equally-weighted portfolio of small CA funds, Big is the equally-weighted portfolio of big CA funds, and VG is the Vanguard Convertible Securities mutual fund *, **, and *** indicate that the coefficient is significantly different from zero at the 10, 5, and 1% levels respectively.

	Panel A: Summary Statistics								Panel B: Correlations																	
	# Obs	Mean (%)	Median (%)	SD (%)	Min. (%)	Max. (%)	Skew	Kurt	CASi^{JP}	CASv^{JP}	CASc^{JP}	CASi^{US}	CASv^{US}	CASc^{US}	Fxret	CISDM	CT	HFR	MSCI	EW	Small	Big
CASi^{JP}	124	0.4	0.5	2.4	-4.1	4.8	-0.02	-0.69	1.00													
CASv^{JP}	124	0.5	0.5	1.1	-1.7	2.3	-0.32	-0.40	-0.04	1.00												
CASc^{JP}	124	-0.9	-0.5	2.4	-6.2	2.9	-0.73	0.06	0.18**	0.34***	1.00											
CASi^{US}	124	0.4	0.1	1.9	-3.0	4.5	0.41	-0.13	0.23***	0.09	0.08	1.00										
CASv^{US}	124	-0.2	0.0	1.1	-2.1	1.6	-0.24	-0.61	-0.03	0.02	-0.09	-0.09	1.00									
CASc^{US}	124	0.3	0.3	2.1	-3.7	4.0	-0.14	-0.80	0.08	0.21**	0.15*	0.28***	0.07	1.00								
Fxret	124	0.1	-0.2	3.0	-7.7	11.1	0.80	1.53	-0.07	-0.20**	0.02	-0.04	0.05	-0.02	1.00							
CISDM	124	1.0	1.1	0.7	-1.9	2.7	-1.35	3.90	0.01	0.31***	0.00	0.27***	0.25***	0.31***	-0.08	1.00						
CT	112	0.9	1.1	1.4	-4.7	3.6	-1.62	4.22	0.14	0.36***	0.10	0.27***	0.04	0.27***	-0.19**	0.80***	1.00					
HFR	124	0.9	1.1	1.0	-3.2	3.3	-1.35	3.84	0.04	0.34***	0.07	0.32***	0.18**	0.34***	-0.04	0.93***	0.81***	1.00				
MSCI	77	1.0	1.0	1.0	-2.2	3.1	-0.71	1.68	0.12	0.39***	0.07	0.37***	0.24**	0.52***	-0.08	0.84***	0.75***	0.82***	1.00			
EW	124	0.9	1.1	1.0	-3.5	3.0	-1.00	2.25	0.01	0.38***	0.02	0.22**	0.26***	0.32***	-0.07	0.92***	0.81***	0.91***	0.81***	1.00		
Small	124	1.0	1.0	1.1	-2.5	3.6	-0.45	0.59	-0.02	0.30***	0.01	0.19**	0.29***	0.31***	-0.04	0.85***	0.70***	0.82***	0.79***	0.93***	1.00	
Big	124	0.9	1.0	1.1	-4.5	2.7	-1.38	3.98	0.03	0.41***	0.03	0.23***	0.21**	0.30***	-0.10	0.89***	0.83***	0.88***	0.79***	0.95***	0.78***	1.00
VG	124	0.7	0.7	3.7	-12.8	10.6	-0.39	1.29	-0.03	0.17*	-0.13	0.07	0.48***	0.29***	0.04	0.55***	0.35***	0.52***	0.44***	0.60***	0.61***	0.52***

Table IV: Regression analysis

This table provides the results of OLS regressions during our sample period from January 1993 to August 2002, allowing for structural breaks and demand-supply effects. The regression analysis proceeds in two steps. In step 1, the dependent variables are the returns on the four convertible arbitrage hedge fund indexes (CISDM, CT, HFR, and MSCI), our equally-weighted index of all the convertible arbitrage (CA) funds in our sample (EW), the equally-weighted portfolio of small CA funds (Small) and the equally-weighted portfolio of big CA funds (Big), while the independent variable is the return on the Vanguard Convertible Securities mutual fund (VG). In the step 2, we regress the residuals obtained from step 1 on the ABS factors (CASi, CASv, CASc), exchange rate factor (Fxret), and the two conditioning variables - structural break dummy (D) and lagged value of supply-demand ratio ($mktaum_{t-1}$) (where the numerator is the total market capitalization of convertible bonds minus the total assets under management (AUM) of convertible bond mutual funds and fixed income convertible hedge funds and the denominator is the total AUM of the convertible arbitrage hedge funds), and the interaction of conditioning variables (D and lmktaum) with ABS factors. *, **, and *** indicate that the coefficient is significantly different from zero at the 10, 5, and 1% levels respectively. p-values are computed using Newey-West (1987) standard errors.

	CISDM	***CT***	***HFR***	***MSCI***	***EW***	***Small***	***Big***
				Panel A: Step 1			
Intercept	0.005***	0.004**	0.005***	0.004***	0.005***	0.006***	0.0004***
VG	0.10***	0.12***	0.13***	0.09***	0.17***	0.18***	0.15***
Adj R^2	30.28%	10.72%	26.06%	19.11%	35.83%	36.26%	26.77%
				Panel B: Step 2			
Intercept	-0.002**	-0.011***	-0.004***	-0.008**	-0.007***	-0.005***	-0.008***
$CASi^{US}$	0.125**	0.344***	0.145**	0.314**	0.204***	0.252***	0.177***
$CASv^{US}$	-0.063	-0.066	-0.167	0.079	-0.068	-0.157	-0.004
$CASc^{US}$	0.053	0.178*	0.176***	-0.278	0.136**	0.116	0.143**
$CASi^{JP}$	-0.033	0.069	-0.022	0.103	0.020	-0.003	0.027
$CASv^{JP}$	0.114	0.573**	0.267*	1.139***	0.259**	0.128	0.354**
$CASc^{JP}$	0.080	0.189	0.111	-0.075	0.143*	0.168**	0.151*
Fxret	-0.014	-0.108***	-0.001	-0.023	-0.017	0.006	-0.038*
D	0.001	-0.003	0.001	-0.001	0.001	0.002	0.001
$Mktaum_{t-1}$	0.00004*	0.0003***	0.0001**	0.0002**	0.0001***	0.0001**	0.0001***
$CASi^{US}$ x D	0.123***	0.061	0.123*	0.138	0.075	0.119*	0.073
$CASv^{US}$ x D	0.208***	0.477**	0.194*	0.254***	0.284**	0.176	0.424***
$CASc^{US}$ x D	-0.015	-0.122	-0.051	0.172	-0.034	-0.119	0.034
$CASi^{JP}$ x D	-0.017	0.055	-0.041	-0.015	-0.017	-0.028	-0.007
$CASv^{JP}$ x D	-0.083	-0.015	-0.157	-0.109	-0.045	-0.154	0.030
$CASc^{JP}$ x D	-0.025	-0.234	-0.101	0.019	-0.097	-0.070	-0.115
$CASi^{US}$ x $mktaum_{t-1}$	-0.004***	-0.009***	-0.003**	-0.007*	-0.006***	-0.008***	-0.006***
$CASv^{US}$ x $mktaum_{t-1}$	-0.002**	-0.009***	-0.001	-0.005	-0.003*	0.001	-0.006***
$CASc^{US}$ x $mktaum_{t-1}$	0.000	-0.001	-0.002***	0.010*	-0.001*	0.001	-0.002***
$CASi^{JP}$ x $mktaum_{t-1}$	0.001*	-0.002*	0.001	-0.004	-0.001	0.000	-0.001
$CASv^{JP}$ x $mktaum_{t-1}$	0.000	-0.007**	0.000	-0.028***	-0.001	0.001	-0.003
$CASc^{JP}$ x $mktaum_{t-1}$	-0.001	0.001	0.000	0.002	-0.001	-0.001*	-0.001
Adj R^2	13.88%	35.25%	19.76%	11.24%	20.32%	8.62%	28.91%

Table V: Out-of-sample analysis

We report the parameter estimates and R^2 from the univariate regression of actual residual return on predicted residual return. The prediction analysis is conducted over the period 9/2002 – 4/2003 for the CA indexes (CISDM, HFR, MSCI, CT), the equally-weighted portfolio of CA funds (EW), the equally-weighted portfolio of small CA funds (Small) and the equally-weighted portfolio of big CA funds (Big). *, **, and *** indicate that the coefficient is significantly different from zero at the 10, 5, and 1% levels respectively.

	α_i	β_i	R^2
CISDM	0.003*	2.32**	52.08%
CT	0.004**	1.41***	84.86%
HFR	0.003	1.32**	62.52%
MSCI	0.007***	1.74***	71.21%
EW	0.004*	1.36*	40.54%
Small	0.002	0.99	33.08%
Big	0.007***	1.63*	43.88%

Table VI: Economic significance

Table VI presents the impact of the ABS factors and the demand-supply factor on convertible arbitrage residual returns during the period 1/1993 – 4/2002. For each variable of interest, we compute the change in monthly index and equally-weighted portfolio residual returns given a one standard deviation change in the variable. For the ABS factors, we hold the demand-supply factor ($mktaum_{t-1}$) as its sample mean. For the demand-supply factor, we hold the ABS factors at their respective sample means.

		Change in residual return for a one standard deviation change in the following factors (%):						
	Index	$CASi^{US}$	$CASv^{US}$	$CASc^{US}$	$CASi^{JP}$	$CASv^{JP}$	$CASc^{JP}$	$Mktaum_{t-1}$
Before structural break (Before 10/1998)	CISDM	0.15%	0.07%	0.05%	-0.04%	0.04%	0.05%	0.12%
	CT	0.04%	0.03%	-0.01%	0.07%	0.29%	-0.04%	0.58%
	HFR	0.22%	-0.01%	0.11%	-0.09%	0.13%	0.01%	0.19%
	MSCI	0.27%	0.15%	0.67%	-0.15%	-0.15%	0.09%	0.02%
	EW	0.03%	0.11%	0.12%	-0.09%	0.18%	0.04%	0.28%
After structural break (beginning 10/1998)	CISDM	-0.07%	-0.16%	0.08%	0.00%	0.14%	0.11%	0.12%
	CT	-0.07%	-0.49%	0.25%	-0.07%	0.30%	0.52%	0.58%
	HFR	0.00%	-0.22%	0.22%	0.01%	0.31%	0.25%	0.19%
	MSCI	0.02%	-0.12%	0.30%	-0.11%	-0.02%	0.04%	0.02%
	EW	-0.11%	-0.19%	0.19%	-0.05%	0.23%	0.27%	0.28%

Figure 1: Assets under Management of Convertible Arbitrage Funds, Long-biased Convertible Funds and Market Capitalization of Convertible Bonds

This figure plots the total market capitalization of convertible bonds, the total assets under management of convertible arbitrage hedge funds, and the total assets under management of convertible mutual funds and long-biased convertible hedge funds between January 1993 and April 2003.

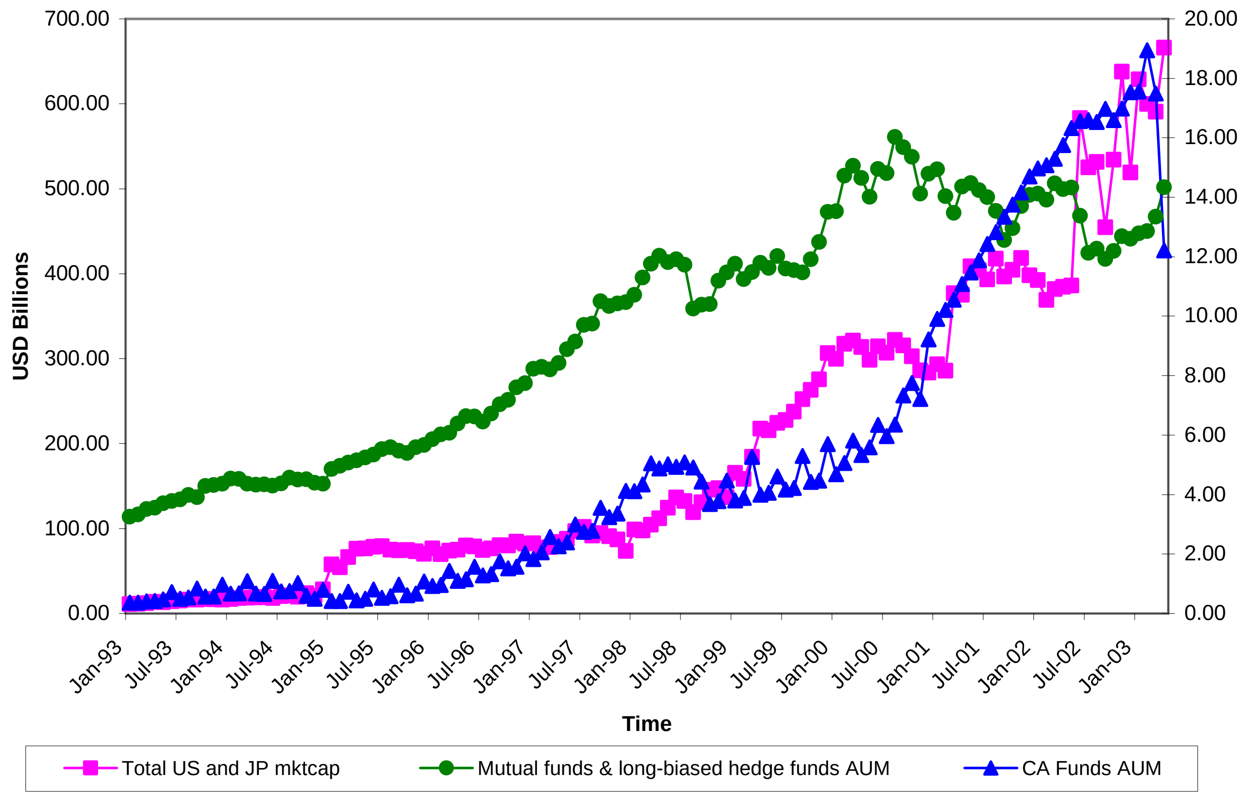


Figure 2: Trend in Convertible Bond Issuance

This figure plots the amount of convertible bond issuance for US and Japan together in billions of US dollars between January 1993 and April 2003. We show the time series of convertible bond issuance from our bond sample ("US and JP conv bond issuance") and from SDC ("SDC conv bond issuance").

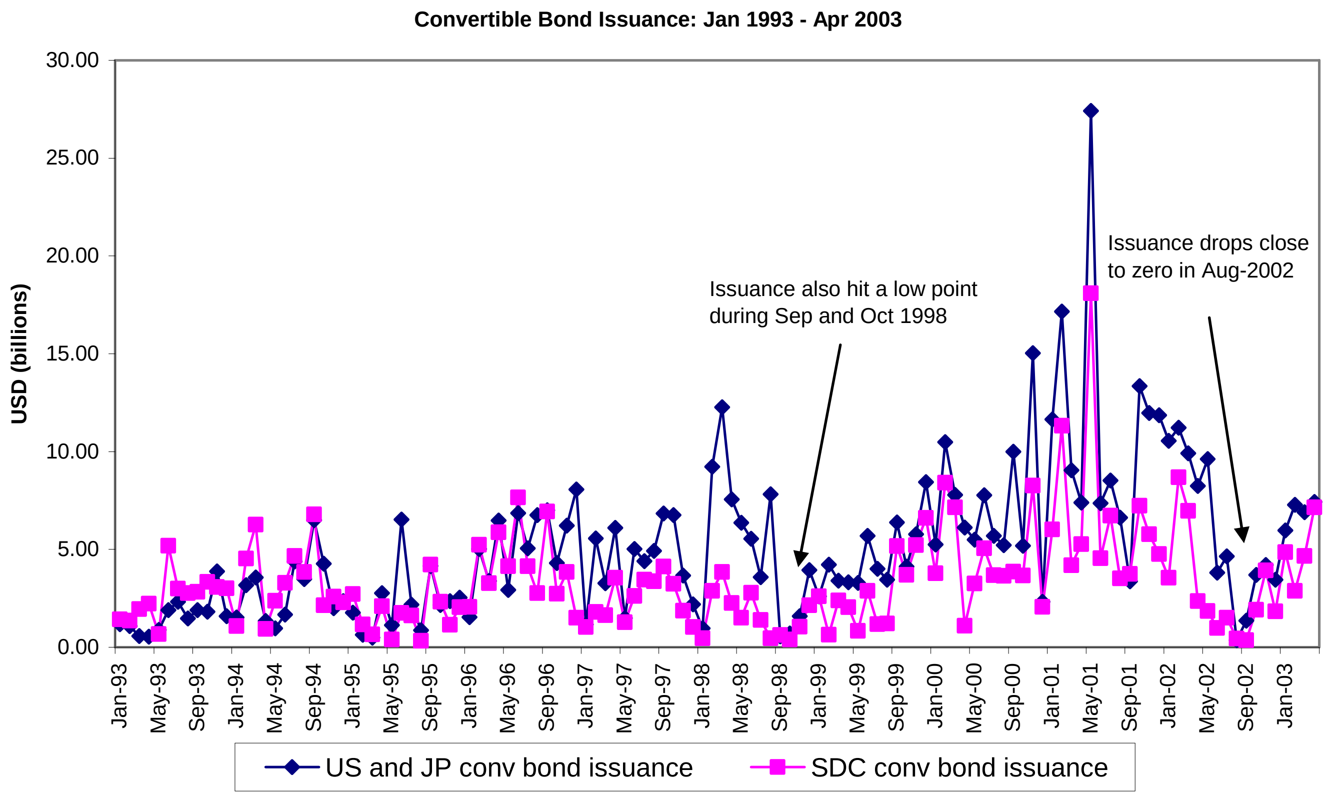


Figure 3: Distribution of Convertible Arbitrage Hedge Funds by Data Sources

This figure shows the percentage of convertible arbitrage hedge funds from the four databases namely CISDM, CT, HFR, and MSCI during our sample period (1993 – 2003).

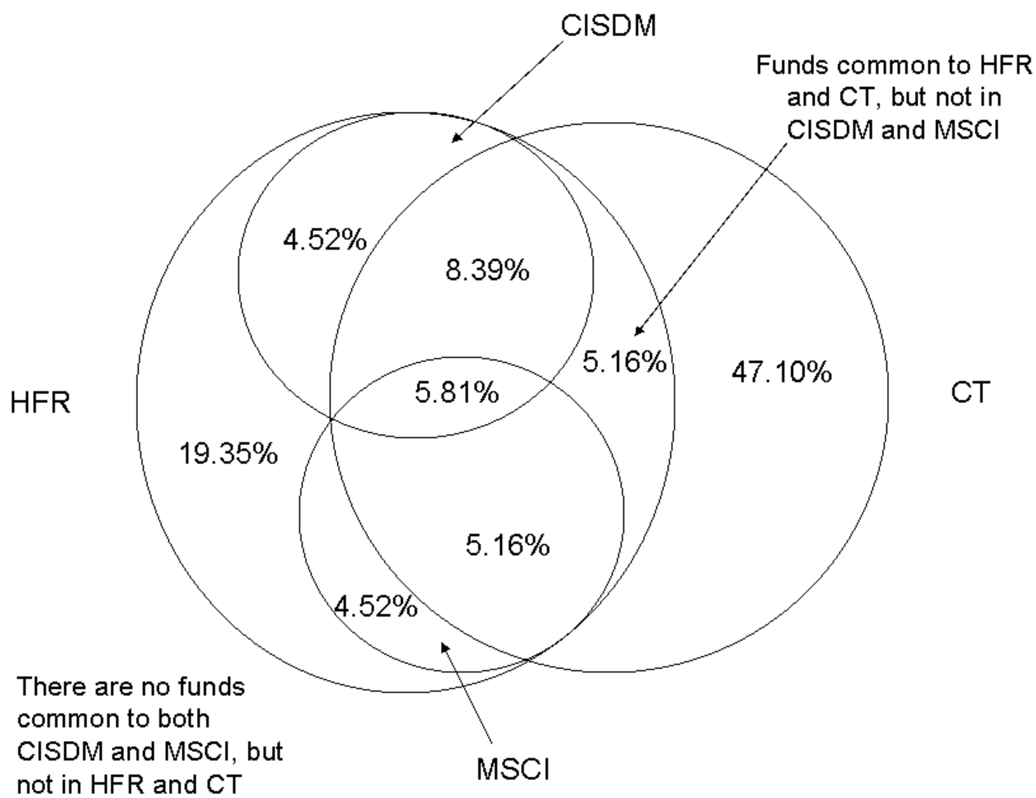


Figure 4: Out-of-Sample Analysis – Actual versus Predicted Returns

These figures plot the actual returns and the predicted returns from our model for the four convertible arbitrage hedge fund indexes (CISDM, CT, HFR, and MSCI), the equally-weighted portfolio of all CA hedge funds in our sample (EW), the equally-weighted portfolio of small convertible arbitrage funds (Small) and the equally-weighted portfolio of big convertible arbitrage funds (Big) for the out-of-sample period between September 2002 and April 2003.

Fig 3a. CISDM

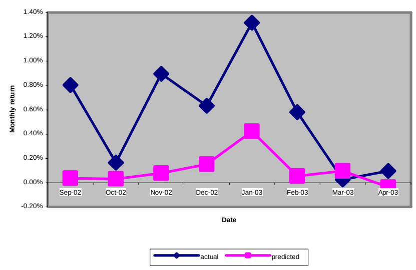


Fig 3b. CT

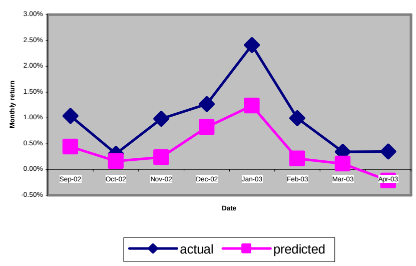


Fig 3c. HFR

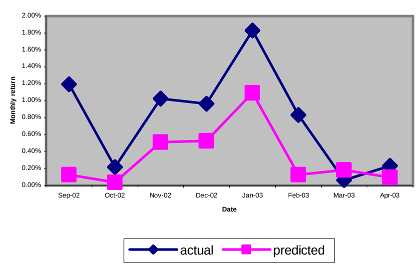


Fig 3d. MSCI

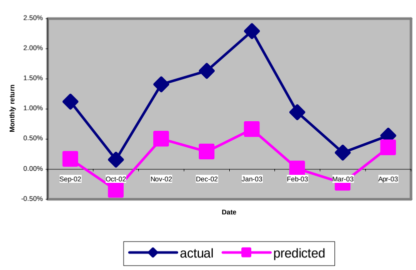


Fig 3e. EW portfolio

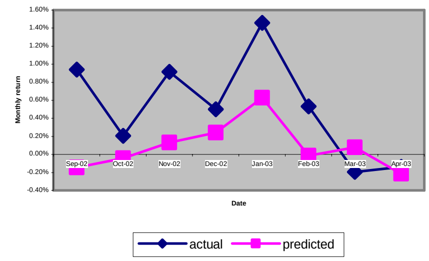


Fig 3f. Small funds

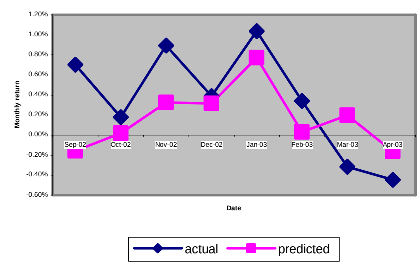
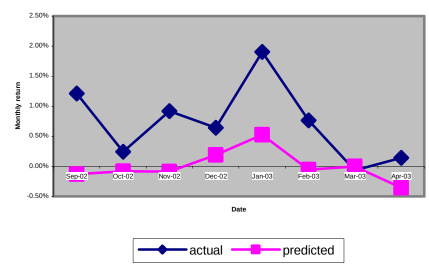


Fig 3g. Big funds



Appendix A: Computation of returns to Carry strategy with different capital requirements

In the first scenario, the manager has *perfect foresight* in terms of capital requirements and can raise capital equal to the maximum bond value during the period of the trade. An example might be the best way to illustrate this treatment of the capital base. Suppose the convertible arbitrageur starts the carry strategy at the end of day *0*, i.e., $\text{carry}_0 > 0$. Further suppose that the trade is terminated at the end of day *T*, i.e., $\text{carry}_T \leq 0$. Changes in the capital requirement are determined based on prices observed at the close of day *1*, day *2*, through to day *T-1* (The capital available at the end of day *T-1* is used to support the position during day *T*, the last day of the trade). During the time between the end of day *0* and the end of day *T-1*, the bond price fluctuates and the capital requirement changes. 'Perfect foresight' means that at the inception of the trade (end of day *0*), the manager obtains capital equal to the maximum bond price occurring between the end of day *0* and the end of day *T-1*. In this scenario, the manager only raises capital once, but he raises sufficient capital to support the trade throughout its entire life. This also means that the capital base remains unchanged throughout the life of trade. Therefore, for a positive carry trade initiated at the end of day *0* and terminated at the end of day *T*, the capital base, C_{max} is

$$C_{\max} = Max(B_0, B_1, ..., B_{T-1}) \tag{1}$$

where, B_0 refers to the bond price paid by the arbitrageur to establish the position, B_1 is the bond price at the end of the first day of the trade and so on.

Under this scenario, the manager will have excess (or idle) capital on days when B_t is less than $C_{\max}$. For simplicity, we assume that idle capital earns the discount rate. Thus, $R_{1,t}$, the total return for day *t* is

$$R_{1,t} = \frac{\text{marked-to-market return} + \text{ interest on short sale proceeds} + \text{interest on excess capital}}{\text{capital base}}$$
$$= \frac{(V_t - V_{t-1}) + \left(SS_{t-1} \times \left(DISC_t - s - dy_t\right)\right) + \max(0, C_{\max} - B_{t-1}) \times DISC_t}{C_{\max}} \quad (2)$$

In the second scenario, the manager is able to raise enough capital on a daily basis. This means that the manager can raise capital "just-in-time" or that idle capital is zero. In this "just-in-time" scenario, the manager only needs the bond value on day *t* as the required capital. This implies that

$$C_t = B_t \quad (3)$$

In this scenario, the manager will have no excess capital and hence, $R_{2,t}$, the total return for day *t* is

$$R_{2,t} = \frac{\text{marked-to-market return} + \text{ interest on short sale proceeds}}{\text{capital base}}$$
$$= \frac{(V_t - V_{t-1}) + \left(SS_{t-1} \times \left(DISC_t - s - dy_t\right)\right)}{C_{t-1}} \quad (4)$$

$R_{1,t}$ and $R_{2,t}$ represents the daily return on *a* positive carry trade in the two scenarios. In practice, carry returns are likely to fall between these two scenarios. The ability to manage capital requirements efficiently reduces idle capital cost and is critical to the consideration of arbitrage limits when leverage is applied.

We implement our trading rule for the positive carry strategy for all eligible bonds in our sample to create an equally-weighted portfolio of positive carry trades over our sample period. The composition of the portfolio changes as old trades are liquidated and new trades are put on. Our positive carry portfolio produces two monthly return series: Carry1 and Carry2. Carry1 is the return series derived from the "perfect foresight" capital base assumption of scenario 1 while Carry2 is derived from the "just-in-time" capital base assumption of scenario 2. These two return series are the ABS factors for PCASi.