Volatility Dispersion Trading

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ABSTRACT

This papers studies an options trading strategy known as dispersion strategy to investigate the apparent risk premium for bearing correlation risk in the options market. Previous studies have attributed the profits to dispersion trading to the correlation risk premium embedded in index options. The natural alternative hypothesis argues that the profitability results from option market inefficiency. Institutional changes in the options market in late 1999 and 2000 provide a natural experiment to distinguish between these hypotheses. This provides evidence supporting the market inefficiency hypothesis and against the risk-based hypothesis since a fundamental market risk premium should not change as the market structure changes.

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I. Introduction

There is growing empirical evidence that index options, especially index puts, appear to be more expensive than their theoretical Black-Scholes prices (Black and Scholes (1973) and Merton (1973)), while individual stock options do not appear to be too expensive (see for instance Bakshi and Kapadia (2003), Bakshi, Kapadia, and Madan (2003), Bollen and Whaley (2004), among others.[1]). An options trading strategy known as dispersion trading is designed to capitalize on this overpricing of index options relative to individual options and has become very popular. Two hypotheses have been put forward in the literature to explain the source of the profitability of dispersion strategy. The risk-based hypothesis argues that the index options are more expensive relative to individual stock options because they bear some risk premium that is absent from individual stock options. An alternative hypothesis is market inefficiency, which argues that options market demand and supply drive option premiums to deviate from their theoretical values. The options market structural changes during late 1999 and 2000 provides a "natural experiment" to distinguish between these two hypotheses. If the profitability comes from some risk factors priced in index options but not in individual equity options, then there should be no change in the profitability following the change in market structure. Our paper investigates the performance of dispersion trading from 1996 to 2005 and finds that the strategy is quite profitable through the year 2000, after which the profitability disappears. These findings provide evidence in support of the market inefficiency hypothesis and against the risk-based explanation.

Dispersion trading is a popular options trading strategy that involves selling options on an index and buying options on individual stocks that comprise the index. As noted in the documentation of EGAR Dispersion ASP[2], "Volatility dispersion trading is es-

[1] See also Branger and Schlag (2004), Dennis and Mayhew (2002) and Dennis, Mayhew and Stivers (2005)

[2] EGAR Techonology is a financial technology company that provides specialized capital markets software solutions, among which Dispersion ASP is designed to provide technical analysis to help with dispersion trading strategies. The citation could be found at *http://www.egartech.com/research_dispersion_trading.asp.*

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sentially a hedged strategy designed to take advantage of relative value differences in implied volatilities between an index and a basket of component stocks. It typically involves short option positions on an index, against which long option positions are taken on a set of components of the index. It is common to see a short position of a straddle or near-ATM strangle on the index and long positions of straddles or strangles on 30% to 40% of the stocks that make up the index." The exposure to volatility risk from the long leg of the strategy on individual stock options tends to be canceled by that of the short leg in index options. In addition, at-the-money straddle or out-of-the-money strangle positions have delta exposures very close to zero. Therefore, by construction, a dispersion strategy that buys index straddles/strangles and sells straddle/strangle positions on individual components is hedged against large market movement and has low volatility risk, which makes it an ideal candidate to bet on the differences between implied volatilities of index and individual options.

One strand of literature has argued that the differences in the pricing of index and individual equity options evidence that various risks, such as volatility risks and correlations risks, are priced differently in index options and individual stock options. Bakshi, Kapadia and Madan (2003) relate the differential pricing of index and individual options to the difference in the risk-neutral skewness of their underlying distributions. Moreover, in Bakshi and Kapadia (2003), they show that individual stocks' risk-neutral distributions are different from the market index because the market volatility risk premium, though priced in both individual options and index options, is much smaller for the individual options and idiosyncratic volatility does not get priced. Recently, Driessen, Maenhout and Vilkov (2006) argue that the profits to dispersion trading results from a risk premium that index options bear and is absent from individual options. They develop a model of priced correlation risk and show that the model generates several empirical implications, including index option returns that are less than individual option returns, which are consistent with previous empirical findings. Thus, they claim that correlation risk premium is negative and index options, especially index puts, are more expensive because they hedge correlation risk.

Another avenue of investigation attributes the puzzle of differential pricing between index and equity options to the limitations or constraints of the market participants in trading options. According to Bollen and Whaley (2004), the net buying pressure present in the index options market drives the index options prices to be higher. Under ideal dynamic replication, an option's price and implied volatility should be unaffected no matter how large the demand is. In reality, due to limits of arbitrage (Shleifer and Vishny (1997), Liu and Longstaff (2000)), a market maker will not sell an unlimited amount of certain option contracts at a given option premium. As he builds up his position in a particular option, his hedging costs and volatility-risk exposure also increase, and he is forced to charge a higher price. Bollen and Whaley show that changes in the level of an option's implied volatility are positively related to variation in demand for the option, and then argue that demand for out-of-the-money puts to hedge against stock market declines pushes up implied volatilities on low strike options in the stock index options market. Gârleanu, Pedersen and Poteshman (2006) complement Bollen and Whaley 's hypothesis by modelling option equilibrium prices as a function of demand pressure. Their model shows that demand pressure in a particular option raises its prices as well as the prices of other options on the same underlying. Empirically, it is documented that the demand pattern for single-stock options is very different from that of index options. Both Gârleanu, Pedersen and Poteshman (2006) and Lakonishok, Lee, Pearson, and Poteshman (2007) show that end users are net short single-stock options but net long index options. Thus single-stock options appear cheaper and their smile is flatter compared to index options.

Therefore, the existing literature has different explanations regarding the expensiveness of index versus individual options. The institutional changes that happened to the options market around late 1999 and 2000, including cross-listing of options, the launch of the International Securities Exchange, a Justice Department investigation and settlement, and a marked reduction in bid-offer spreads, provide a natural experiment that allows one to distinguish between these hypotheses. Specifically, these changes in the market environment reduced the costs of arbitraging any differential pricing of individual equity and index options via dispersion trading. If the profitability of dispersion trading is due to miss-pricing of index options relative to individual equity options, one would expect the profitability of dispersion trading to be much reduced after 2000. In contrast, if the profitability of dispersion trading is compensation for a fundamental risk factor, the change in the option market structure should not affect the profitability of this strategy.

In this paper, we investigate the performance of dispersion trading from 1996 to 2005 and examine whether the profits to dispersion strategy decreased after 2000. We find that dispersion trading is quite profitable through the year 2000, after which the profitability disappears.

We initially examine the risk/return profile of a simple dispersion trading strategy that writes the at-the-money (ATM) straddles of S&P 500 and buys the ATM straddles of S&P 500 components. We find the average monthly return decreases from 24% over 1996 to 2000 to -0.03% over 2001 to 2005. Moreover, the Sharpe ratio also decreased from 1.2 to -0.17, and Jensen's alpha decreases from 0.29 to -0.04. A test of structural change supports the changing profitability hypothesis as well. These results suggests that the differential pricing of index versus individual stock option must have been caused at least partially by option markets' inefficiency.

Next, we investigate several refined dispersion strategies that are designed to deliver improved trading performance and check whether the changing profitability results are affected. First, we examine a more complicated dispersion trading strategy that takes into the account the change of correlation over time by conditioning the trades on a comparison between the "implied correlation," an average correlation measure inferred from the implied volatilities of index options and individual options, and "forecasted correlation," which are estimates of future realized correlation. Second, due to concerns about liquidity and transaction costs, we further restrict the equity options traded to be a subset of the index components. Principal Component Analysis is used to determine the most effective 100 individual stocks that capture the main movement of the index. Third, we examine a delta-neutral strategy that will hedge daily the delta positions of the dispersion strategy using underlying stocks. Finally, we examine the dispersion strategy that buys at-the-money individual straddles and writes out-of-the-money index strangles, which are suggested to be the cheapest individual options and most expensive index options (see, for example, Bollen and Whaley (2004) and Gârleanu, Pedersen and Poteshman (2006)). The Sharpe ratio increases to 0.89 after transaction costs for this strategy, which is in line with the demand/supply explanation for the differential pricing puzzle.

We find that the performance for all the refined dispersion strategies improved as expected. However, we have the same results as the simplest strategy that the profitability disappears after 2000. These results imply that the changing of market conditions around late 1999 and 2000 has led to the profits to dispersion strategy to be arbitraged away, which suggests that correlation risk premium cannot fully explain the differential pricing between index options and individual options. The improved market environment should have no effect on any fundamental market risk premium and therefore would not have changed the profitability of a trading strategy if profits are driven by correlation risk premium. Hence, we find evidence in support of the market inefficiency hypothesis.

The remainder of the paper is organized as follows. Section II describes that data used for the empirical analysis. Section III describes the properties of the dispersion strategy and provides an overview of the regulatory changes that affected option markets around late 1999 and 2000. Section IV provides the methodological details and presents the returns of a naive dispersion strategy. Section V presents empirical results of several improved version of dispersion strategies. Section VI discusses the implication of the results and provides further validations. Section VII briefly summarizes and concludes.

II. Data

The empirical investigation focuses on the dispersion trading strategy using S&P 500 index options and individual options on all the stocks included in the index. We obtained options data from the OptionMetrics Ivy database. For each option, we have the option id number, closing bid and ask prices, implied volatility, delta, vega, expiration date, strike price, trading volume, and a call/put identifier. Our options data cover the 10-year period from January 1996 to December 2005. Stock prices, returns, shares outstanding, as well as dividend and split information for the same time period are from the Center for Research in Security Prices (CRSP). Because we focus on options with one month to expiration, we use one-month LIBOR rate from DataStream as the risk-free interest rate.

The S&P 500 is a value-weighted index that includes a representative sample of 500 leading companies in leading industries of the U.S. economy. The list of constituent companies may change over time whenever a company is deleted from the index in favor of another. In our sample, 288 such additions and deletions took place. We reconstruct the index components and corresponding index weights for the entire sample period. The weight for stock i is calculated as the market value (from CRSP) of company i divided by the total market value of all companies that are present in the index.

To minimize the impact of recording errors, the options data were screened to eliminate (i) bid-ask option pairs with missing quotes, or zero bids, or for which the offer price is lower than the bid price, and (ii) option prices violating arbitrate restrictions. Table 1 summarizes the average option prices, measured as the average of the bid and ask quotes, open interest, volume, and bid-ask spread ratio measured as bid-ask spread over bid-ask midpoint for both index and individual calls and puts for 7 moneyness categories, for which K/S varies from 0.85 to 1.15. Consistent with previous studies (e.g., Gârleanu, Pedersen and Poteshman (2006)), out-of-the-money put options and in-the-money call options have the highest trading volume and open interest among index options. For individual stock options, at-the-money call options and put options have the highest volume and open interest. Compared to the index options, the volume and open interest are more evenly distributed among all moneyness categories for individual equity options. In addition, all options have quite high transaction costs. The median bid-ask spread ratio is 6.78% for index options and 9.52% for individual options.

One of the improved dispersion trading strategy is implemented based on a comparison between implied correlation (the average correlation among index component stocks implied from option premiums) and benchmark correlation forecasts. The computation of implied correlation requires data on implied volatilities of SPX index options and individual options on SPX components. We obtain implied volatilities directly from OptionMetrics for call options and put options with the same strike price and are closest to at-the-money. We then average these two implied volatilities as the implied volatility measure. Two volatility measures are used to derive benchmark correlation forecast estimates to compare with implied correlation. The first one is the historical volatility measure. The historical variance is calculated as the sum of squared daily returns over the 22-day window prior to the investment date. We get daily returns for individual stocks and for the S&P 500 from CRSP and OptionMetrics respectively. The other volatility measure is the predicted volatility over the remaining life of the option from a GARCH(1,1) model estimated over five years of daily underlying stock returns leading up to the day of investment. Both measures are transformed into annual terms in calculation.

III. Dispersion trading and the options market

A. Dispersion trading strategies

In the subsection I argue that options market has become more competitive since the structural changes around 1999 and 2000. This exogenous efficiency improvement event provides a natural experiment to test whether the profits to dispersion trading are driven by the correlation risk premium embedded in index options or result from the mispricing of index options relative to individual equity options.

As described earlier in Section I, dispersion strategy involves short index options positions, against which long positions are taken on individual options of index components. For an index $I = \sum_{i=1}^{N} \omega_i S_i$, assume that each individual component stock follows a geometric Brownian motion,

$$dS_i = \mu_i S_i dt + \sigma_i S_i dW_i \tag{1}$$

where W_i is a standard Wiener process. The variance of the index can be approximately calculated from the following formula

$$\sigma_I^2 = \sum_{i=1}^{N} \omega_i^2 \sigma_i^2 + 2 \sum_{i=1}^{N} \sum_{j>i} \omega_i \omega_j \sigma_i \sigma_j \rho_{ij} \tag{2}$$

where σ_I^2 is the index variance, ω_i for $i = 1, 2, ..., N$ is the weights for stock i, σ_i^2 is the individual stock variance, and ρ_{ij} is the pairwise correlation between the returns of stock i and stock j. Assuming that $\rho = \rho_{ij}$ for $i \neq j, i, j = 1, ...N$, equation (2) allows us to solve for a measure of average correlation if we know the volatilities of all constituents and the index. In particular, the implied average correlation is

$$\bar{\rho} = \frac{\sigma_I^2 - \sum_{i=1}^{N} \omega_i^2 \sigma_i^2}{2 \sum_{i=1}^{N} \sum_{j>i} \omega_i \omega_j \sigma_i \sigma_j}. \tag{3}$$

Since the dispersion strategy involves long positions on individual volatilities and short positions on index volatility, it will make profits when the realized volatilities of individual stocks are high and the realized volatility of the index is low. In other words, the strategy loses little on the short side and makes a lot on the long side if large "dispersion" among constituent stocks is achieved. This will happen when the realized average correlation turns out to be lower than implied correlation. Thus the main source of risk that this strategy is exposed to can be interpreted as the variation of correlation between individual component stocks.

Therefore, the profits to dispersion strategy could possibly come from the negative correlation risk premium, as argued by Driessen, Maenhout and Vilkov (2006). On the other hand, the profits could come from the overpricing of index options relative to individual stock options, or maybe both. As long as the overpriced index volatilities play a part here, this implies that options market is inefficient. And the reasons behind overpricing could be the excessive institutional demand of index options for portfolio protection and the supply of individual stock options by covered call writing. Previous studies, such as Bollen and Whaley (2004) and Gârleanu, Pedersen and Poteshman (2006) have found empirical evidence supporting that the demand and supply in options market could push option prices to levels inconsistent with the usual no-arbitrage pricing relations. In this paper, we would like to distinguish between these two possibilities. The structural changes that happened to the options market around late 1999 and 2000 turns out to be a natural experiment that can help accomplish this task.

B. Options market structural changes

Since late 1999, options markets have experienced a series of dramatic changes in the regulatory and competitive environment. These changes are described thoroughly in Defontnouvelle et al. (2000). Here, we summarize the major relevant aspects. In 1999, the U.S. Department of Justice initiated an investigation focusing on whether options exchanges had reached an implicit agreement to not compete for trading flows of options that are previously listed on other exchanges. After that, class action lawsuits were filed against the exchanges alleging anticompetitive practices. In addition, SEC instituted administrative proceedings and requested a market linkage plan to be proposed to improve options markets' execution quality. In response to these actions, the four option exchanges (AMEX, CBOE, PCX and PHLX) began to cross list many options that had been exclusively listed on another exchange. The listing campaign started on August 18,1999, when CBOE and AMEX announced the listing of DELL options, which had been previously listed only on the PHLX. Soon, a series of sizable competitive listings announcements were made by all four exchanges. De Fontnouvelle, Fishe and Harris (2003) show that 37% of equity option volume had shifted from single- to multiple-exchange trading by the end of September 1999. And this effect continued in the following year. In September 2000, four exchanges reached an anti-trust settlement that require them to spend $77 million on surveillance and enforcement of trading rules. The class action suit was also settled around the same time. Moreover, the International Securities Exchange (ISE), an all electronic options market, was launched in May 2000, which further intensified competition in options market. By October 2000, the ISE traded almost all active options classes.

Several papers have studied the effects of these structural changes and have shown that the options market execution quality improved a lot after them. De Fontnouvelle, Fishe and Harris (2003) study the bid-ask spreads for 28 option classes that were multiply listed in August 1999. They find that, immediately after multiple listing, the average effective spread fell 31.3% and 38.7% for calls and puts respectively. Quoted spreads fell by more than 50%. The reductions are also relatively permanent with little reversion after one year. Their evidence supports the hypothesis that the interexchange competition increased after the structural changes in 1999 and 2000 had reduced the option transaction costs dramatically. In related work, Hansch and Hatheway (2001) examine the trade and quote data for 50 of the most active equity option classes between August 1999 and October 2000. They find that trade-through rates (trade-throughs occur when trades execute at prices outside of prevailing quotes), quoted spreads, and effective spreads fall significantly between August 1999 and October 2000. Therefore, the existing evidence shows that the institutional changes around late 1999 and 2000 had made the options market more efficient. As stated in SEC concept release (No. 34-49175, Section II.C),"Exchange transaction fees for customers have all but disappeared. Spreads are narrower. Markets have expanded and enhanced the services they offer and introduced innovations to improve their competitiveness."

To check whether the bid-ask spreads for our sample have also become narrower after the institutional changes , we examine the bid-ask spread ratios of our sample option series from 1996 to 2005. Figure 1 displays the trend of the monthly median spread ratios for call options and put options respectively. Both graphs show a clear drop of the median spread ratios around 2000. In addition, the drop is not temporary, as the spread ratios maintained the lower level through 2005. We further test whether the drop is statistically significant. Table 2 shows that the median bid-ask spread for call options is 10.86% before 2001. After 2001, it decreases to 7.62%. A t-test of mean difference returns 10.10, which strongly rejects the hypothesis that the spread ratio did not change. Similarly, we find the average bid-ask spreads for put options drop from 12.78% to 9.12%, also with a strongly significant t-statistic of 8.46. Our results are consistent with previous studies that the bid-ask spreads became much smaller after the multiple listings and introduction of the ISE. The trading volume of options have also increased dramatically. The average trading volume for call options is 111 before 2001, which goes up to 356.8 after 2001. Therefore, it is confirmed that option market has become more efficient since 2001 and reduction in the transaction costs of options has attracted a lot more funds to enter option market. These option market changes reduced the cost of dispersion trading, and thus suggest the possibility that the profitability of dispersion trading was "arbitraged away".

Thus, investigating whether its return/profitability has changed since 2001 allows us to examine the source of profits to dispersion trading.We expect to observe a change in the profitability of dispersion strategy around 2000 if the market inefficiency hypothesis is true. Otherwise, if the profits to dispersion trading are a fundamental market risk premium for bearing correlation risk, changing market conditions and entry of capital into the options market should not have affected the profitability.

IV. A Naive Dispersion Strategy

In this section, we describe the implementation details of a naive dispersion strategies and compare its return for the pre-2000 period and post-2000 periods. Starting from January, 1996, on the first trading day following options' expiration date of each month, a portfolio of near-ATM straddles on S&P500 index is sold and a portfolio of near-ATM straddles on S&P500 component stocks is bought. All options traded in this strategy expire in the next month (with approximately one-month expiration). We hold the portfolio until the expiration date, realize the gains/losses and then make investment on the next trading day following expiration. This is repeated every month, giving us a total of 120 non-overlapping trading periods of either 4 or 5 weeks in length, over the whole 10-year sample period from 1996 to 2005.

We choose approximately at-the-money (ATM) straddle positions to trade because a straddle position is not sensitive to the underlying stock movement (low delta) while subject to the volatility change of its underlying stock. We select call options and put options with the strike price and closest to the stock price as of the investment date. Denote t as the investment date and T as the expiration date. The payoff $\Pi_{t,T}^{long}$ from the long side of this strategy is

$$\Pi_{t,T}^{long} = \sum_{i=1}^{N} n_{i,t} |S_{i,T} - K_{i,t}|, \tag{4}$$

where $S_{i,T}$ is the price of stock i at expiration T, $K_{i,t}$ is the strike price, and $n_{i,t}$ is the number of individual straddles traded at t. The payoff from the short side of the straddle is

$$\Pi_{t,T}^{short} = |S_{I,T} - K_{I,t}|, \tag{5}$$

where $S_{I,T}$ and $K_{I,t}$ are the index level at expiration and the index option strike price, respectively. We define $n_{i,t}$ as

$$n_{i,t} = \frac{N_{i,t} S_{I,t}}{\sum_{i=1} N_{i,t} S_{i,t}}, \tag{6}$$

where $N_{i,t}$ is the number of shares outstanding of stock i. Because $S_{I,t} = \sum_{i=1}^{N} n_{i,t} S_{i,t}$, we choose $n_{i,t}$ as the number of shares bought for the straddle on index component i so that the payoff of the index straddle is matched as closely as possible to the total payoff of the individual straddles. In this way, the strategy, by construction, is protected against large stock market movement.

The return of the strategy over the risk-free rate is calculated as follows:

$$R_{t,T} = \begin{cases} \frac{V_T - V_t}{V_t} - e^{r(T-t)} & if \quad V_t \geq 0, \\ -\frac{V_T - V_t}{V_t} + e^{r(T-t)} & if \quad V_t < 0, \end{cases}$$

where $V_T = \Pi_{t,T}^{long} - \Pi_{t,T}^{short}$ is the payoff from the portfolio at expiration, $V_t = \sum_{i=1}^{N} n_{i,t}(Call_{i,t} + Put_{i,t}) - (Call_{I,t} + Put_{I,t})$ is the initial price paid for the portfolio,r is the continuously compounded one-month LIBOR rate at investment date (where the proceeds is invested in a risk free asset if $V_t < 0$.

In this strategy, the index options are European-style and individual options are American-style. Therefore, assuming the option portfolio is hold till expiration might underestimate the resulting returns since we are selling index options and buying individual options. Subsection B.1 below demonstrates that the bias from ignoring the American-style exercise of the individual equity options is too small to affect our conclusions.

Net of transaction costs, the rate of return is

$$NR_{t,T} = R_{t,T} - \frac{\delta_t}{|V_t|}, \tag{7}$$

where δ_t is the transaction costs (being half the bid-ask spread) at initial investment. We calculate the rate of return for all other versions of dispersion strategies in the same fashion.

A. Returns

Panel A of Table 3 summarizes the resulting returns of the naive dispersion strategy over the sample period. The Sharpe ratio is shown to measure the profitability of the resulting return series. Because Sharpe ratio works best if the return follows a normal distribution, we also test the normality of the resulting return series. Besides, we reports the regression coefficients of the following two regressions:

$$NR_t = \alpha + \beta(R_{m,t} - R_{f,t}) + \epsilon_t, \tag{8}$$

where NR_t is the excess return on the dispersion strategy at investment date t and $R_{m,t} - R_{f,t}$ is the market excess return at t, and

$$NR_t = \alpha + \beta(R_{m,t} - R_{f,t}) + \theta(\sigma^2_{realized} - \sigma^2_{model-free}) + \epsilon_t, \tag{9}$$

where $\sigma^2_{realized}$ is the realized return variance of S&P 500 over the month and $\sigma^2_{model-free}$ is an estimate of the model-free variance of measured as VIX from CBOE, both scaled by a factor of 100. equation (8) is the CAPM regression which examines the return of the dispersion strategy controlling for the market risk factor. equation (9) extends equation (8) by adding a factor that mimics the volatility risk. Carr and Wu (2008) have shown that variance risk premium can be quantified as the difference between the realized variance and a synthetic variance swap rate (VIX in the case of S&P 500). Therefore, we add $\sigma^2_{realized} - \sigma^2_{model-free}$ to CAPM regression to control for both the market risk and the volatility risk. If the strategy is profitable, the intercepts should be significantly positive for both regressions.

As seen from the table, over the 120 trading periods, the dispersion strategy yields an average monthly return of 10.7%, with a t-statistic of 1.867. Its Sharpe ratio is 0.59, which is slightly higher than the Sharpe ratio of S&P 500 index (0.47 over the same sample period). The normality test supports the hypothesis that the return is normally distributed. Therefore, the usage of Sharpe ratio as a performance measure is justified. Alpha from CAPM regression is 0.113, with a t-statistic of 1.92. When the volatility risk factor is added to the regression, alpha drops to 0.03 with a t-statistic of 0.49. We find that the coefficient on the volatility risk factor is -0.06 and significant. This implies that the volatility risk of the short positions on the index options are not canceled completely by the long positions on the individual equity options. The strategy still loads quite a bit on the volatility risk premium. It is also worth mentioning that the coefficient of the market factor becomes more negative after volatility risk factor is taken into account. This could be explained by the negative correlation between the market factor and the volatility risk factor (Carr and Wu (2008)). Overall, the naive strategy is only marginally profitable over the whole sample period. When both market risk and volatility risk are controlled, the strategy does not generate abnormal returns.

To investigate whether the profitability of the dispersion strategy changed around the end of 2000, we reexamine the performance of the strategy over two subperiods, 1996–2000 and 2001–2005. We find a dramatic difference in the performance over the two subperiods. The naive dispersion strategy is quite profitable over the subperiod 1996–2000. The average monthly return is 24% with a t-statistic of 2.68. The Sharpe ratio is 1.2 and the intercepts from the two regressions are both significantly positive, being 0.29 and 0.20 respectively. However, the profitability appears to disappear over the subperiod 2001–2005, during which the average return becomes -2%, the Sharpe ratio drops to -0.17 and the intercepts from equation (8) and equation (9) decrease to -0.04 and -0.12, respectively. All performance measures suggest that the naive dispersion strategy performed poorly over the subperiod 2001–2005.

Another interesting finding is that the beta coefficients change from a large negative number to close to 0 over the two subperiods. We take this as some evidence in support of the market inefficiency hypothesis that we discussed earlier in Section III. A negative beta coefficient means that the return of the strategy is negatively correlated with the market return. Since the demand for portfolio protection and thus for index put options is usually higher during market down turns, it is possible that index options are more overpriced during bear market period and the dispersion strategy will be negatively correlated with the market return, as is the case for the pre-2000 period. After 2000, the market gets more efficient and the arbitrage profits were traded away. Thus the returns of the strategy are not correlated with the market return any more.

We further test whether this change of profitability is statistically significant. Three tests are implemented and reported in Table 4. First, a basic t-test of difference in average returns is calculated. The test statistic is -2.36, which suggests that the return of the dispersion strategy is significantly lower over the period 2001–2005. Next, we run the following regression:

$$NR_t = \alpha + \beta(R_{m,t} - R_{f,t}) + \gamma \cdot I(t \geq 2001) + \epsilon_t, \tag{10}$$

where $I(t \geq 2001)$ is a dummy variable indicating whether the time period is after 2000. We find the estimation coefficient γ to be -0.28 with a p-value of 0.015. This means that α is 28% smaller over the time period after 2000 than before 2000. Last, we add the variance risk factor:

$$NR_t = \alpha + \beta(R_{m,t} - R_{f,t}) + \theta(\sigma^2_{realized} - \sigma^2_{model-free}) + \gamma \cdot I(t \geq 2001) + \epsilon_t. \tag{11}$$

Consistently, we find that γ is -0.31 with a p-value of 0.006. Therefore, we find that the profitability of the naive dispersion strategy has disappeared after 2000, which agrees with the market inefficiency hypothesis. If the profits to dispersion strategy results exclusively from the correlation risk embedded in index options, there is no reason for the profits to go away as the market structure changes around 2000. On the other hand, if market inefficiency explains the source of the profits to dispersion strategy, it is likely that improved market competitiveness make the dispersion opportunities to be arbitraged away.

B. Robustness checks

B.1. Does early-exercise matter?

The naive dispersion strategy involves writing (European) index options and buying (American) options on the component stocks. We calculate the return of this strategy assuming that all options are held to expiration and ignore the possibility of early exercise of the purchased equity options. This is likely to understate the returns of the strategy. However, we are mostly interested in whether the profitability differed before and after 2000. This issue can affect the main result only if the bias due to ignoring the possible early exercise of the American options differs before and after 2000, which seems unlikely. Nonetheless, to address this concern, we recalculate the returns of the strategy taking into account the early exercise premium of the American options. Assuming the total early exercise premium is x, the return of the strategy adjusted for the American features of the individual options is now calculated as

$$R^A_{t,T} = \begin{cases} \frac{V_T - V_t}{V_t - x} - e^{r(T-t)} & \text{if} \quad V_t \geq 0, \\ -\frac{V_T - V_t}{V_t - x} + e^{r(T-t)} & \text{if} \quad V_t < 0. \end{cases}$$

The net return after transaction costs $NR^A_{t,T}$ is defined in the same fashion as before.

We estimate the early exercise premium as the difference between the option price (bid-ask midpoint) and the Black-Scholes model price of an otherwise identical option using the implied volatility provided by OptionMetrics. For the sample options traded in the naive dispersion strategy, about 12.2% of them have positive early exercise premia, with 4.36% call options and 7.84% put options. The premia are on average 4.5% of the option price. Panel B of Table 3 reports the return of the naive dispersion strategy when the early exercise premia are included in return calculation. We observe that the resulting performance of the strategy change only slightly. The average returns, Sharpe ratios, and alpha's all get slightly better. Yet the difference in profitability before and after 2000 still remain significant. The tests of changing profitability shown in Table 4 are almost the same as previous results. Therefore, the early exercise effect is minimal, and ignoring the early exercise feature of the individual stock option does not have any impact on our results.[3]

B.2. Does the selection of break points matter?

The series of structural changes to the options market did not happen simultaneously. As discussed in Section III, the competition for trade flows first started on August 18th, 1999. It leads to the shift and increase of the trading volume for option series that were previously singly-listed. As shown in De Fontnouvelle, Fishe and Harris (2002), this effect went on until 2000. In addition, the introduction of the ISE in May 2000 and the anti-trust settlement among four exchanges in September 2000 continued to enhance the competitiveness of options market through the end of 2000. Thus the exact break point that should be used bit ambiguous.

To show that our results are not sensitive to the choice of the break point, we re-examine the performance of the naive dispersion strategy using two other break points: (i) September 1999, and (ii) January 2002. The first break point is the earliest plausible time. Options' cross listings began in August 1999 and continued until the end of September 1999. De Fontnouvelle, Fishe and Harris (2002) show that 37% of all equity option volume had shifted from single- to multiple-exchange trading by the end of September. In addition, the quoted and effective spreads decreased a significantly

[3] We also recalculate the returns for all other dispersion strategies in the paper and find no significant changes.

between the pre-multiple-listing period in August 1999 (8/2/1999 to 8/20/1999) and the immediate post-multiple-listing period running through the end of September 1999. Thus, September 1999 is selected as the earliest possible time point for market efficiency improvement. The second break point is selected because January 2002 is the deadline that the SEC set the for implementation of the linkage plan for option exchanges. Hansch and Hatheway (2001) show that trade-through rates, quoted spreads and effective spreads fell between August 1999 and June 2000. Further, Battallo, Hatch and Jennings (2004) complement their study and find that the these execution quality measures decrease again between June 2000 and January 2002. Therefore, we choose January 2002 as the latest plausible time point to examine whether the trading performance of dispersion strategies reduced significantly.

The returns of the naive dispersion strategy based on different breakpoints are presented in Panel C and Panel D of Table 3. For both breakpoints, we find the same pattern as the original breakpoint (December/2000), i.e. the strategy yields a significant higher return before the breakpoint and then becomes unprofitable. For the first breakpoint, the average return is 0.27 and 0.01 respectively for the pre- and post-breakpoint periods, almost the same as those for the original breakpoint (0.24). For the second breakpoint, the average return is 0.17 and -0.001 before and after the breakpoint. This suggests that the performance of the strategy seems to have been getting worse gradually from the start of the structural change to the end, especially during 2001. Thus, when January 2002 is selected as the breakpoint, the mean return during the pre-breakpoint period is dragged down because of the deteriorating performance of the strategy in 2001. The tests of structural change in Table 4 confirm our prediction. All three tests are strongly significant for the first breakpoint (September/1999). The tests are marginally significant using the second breakpoint because of the lowered returns generated during 2001. These findings also suggest that the profits to the dispersion strategy were not arbitraged away suddenly right after the cross listings in late 1999. It is until the end of 2000 that the profits finally disappeared. Our selection of the breakpoint (December/2000) is therefore appropriate.

V. Improved Dispersion Strategies

In last section, we show that a naive dispersion strategy is profitable before 2000 and then loses its profitability. Now, we will make several efforts to improve the trading performance via more sophisticated dispersion strategies and examine whether the profitability still decreases significantly before and after 2000.

A. Dispersion Trading Conditional on Correlation

Essentially, a dispersion trading strategy takes long positions on the volatility of index constituents and short positions on index volatility. In general, index options are priced quite high compared to individual options. As a result, the index implied volatility is so high that the implied correlation calculated from equation (3) is higher than the realized correlation between individual stocks. One makes money on the dispersion strategy because profits on the long side exceed losses on the short side most of the time. However, there are also periods when the reverse scenario occurred. In that case, the dispersion trade tends to lose money, and it is the reverse dispersion trade that we should take. Therefore, to optimize the strategy, we want to make our trading strategies conditional on the implied correlation estimates from the option prices.

To implement this strategy, on each trading date, we compare implied correlation with two benchmark correlation forecast measures of future realized correlation and decide whether the dispersion trade or the reverse dispersion trade should be undertaken.

We derive the two benchmark measures of future correlation by plugging into equation (3) either (i) historical volatilities or (ii) volatilities forecasts using GARCH(1,1) models. The historical volatilities are calculated as the sum of squared daily log-returns over the 22 trading days prior to the investment date:

$$RV_t = \sum_{i=1}^{22} r_{t-i}^2. \qquad (12)$$

For GARCH-forecasted volatility, we first estimate the following GARCH(1,1) model using log daily returns over the 5 years prior to the investment date:

$$\begin{aligned} r_t &= \mu + a_t, \\ a_t &= \sigma_t \epsilon_t, \\ \sigma_t^2 &= \alpha_0 + \alpha_1 a_{t-1}^2 + \beta_1 \sigma_{t-1}^2, \end{aligned} \qquad (13)$$

where $\epsilon_t \sim N(0,1)$. Then we forecast the volatility over the remaining life of the option as

$$GV_t = \sum_{h=1}^{T} \sigma_{t+h}^2, \qquad (14)$$

where T is the length of maturity of the option and

$$\begin{aligned} \sigma_{t+1}^2 &= \alpha_0 + \alpha_1 a_t^2 + \beta_1 \sigma_t^2, \\ \sigma_{t+h}^2 &= \alpha_0 + (\alpha_1 + \beta_1)\sigma_{t+h-1}^2, \text{ for } 1 < h \leq T. \end{aligned} \qquad (15)$$

We then enter either the dispersion or the reverse dispersion trade based on a comparison of implied correlation and forecasted correlation on the investment date. Specifically,

if $FC_t > (1.10)IC_t$, enter the dispersion trade (long index straddles and short individual straddles. Alternatively, if $FC_t \leq (1.10)IC_t$, then short dispersion (long individual straddles and short index straddles).

Here, FC_t and IC_t are the forecasted correlation (HC_t or GC_t) and implied correlation at investment date respectively. Because there is on average a long dispersion bias (meaning implied correlation is higher than realized correlation), we only reverse the trades if the forecasted correlation is at least 10% higher than the implied correlation.

Since the reverse trades will involve purchased European-style options (index options) and written American-style options (stock options), assuming the option portfolio is hold till expiration overestimates the resulting return to some extent. Yet this happens for less then 10% of the trades (10 out of 120 for the *HC* case and 8 out 120 for the *GC* case). So the early-exercise effect is minimal. Thus we stick to the original assumption and avoid going through the complicated exercising procedure. The results are presented Panel A and Panel B of Table 5. Conditioning the trading strategy on the implied correlation improves the trading results. The mean returns increase to 12.7% and 14.1% when historical and GARCH-forecasted correlations are used to forecast future correlation respectively. Sharpe ratios increase to 0.70 and 0.79 respectively. Consistently, α increases to 0.14 (HC) and 0.15 (GC) for equation (8), and 0.04 (HC) and 0.09 (GC) for equation (9), when conditioning trades are undertaken.

Therefore, we find that adjusting dispersion strategies based on implied correlation helps improve the performance of the naive strategy. However, just as with the naive dispersion strategy, the performance of the conditioning dispersion strategies differs over the two subperiods 1996–2000 and 2001–2005. When trades are based on comparing historical correlation with implied correlation, the Sharpe ratio is 1.17 before 2001 and 0.12 after 2001. Similarly, when GARCH-forecasted correlation is used as the benchmark, the Sharpe ratio decreases from 1.38 for the subperiod 1996–2000 to 0.07 for the subperiod 2001–2005. We further examine whether the differences in returns between the two subperiods are statistically significant. As presented in Table 6, t-statistics are 1.92 and 2.33, supporting the hypothesis that the returns are significantly lower during the later subperiod. The estimated γ coefficients for the dummy regression of equation (10) are -0.23 and -0.27, respectively, for these two benchmarks, and are both significant at 5% level. Similarly, the estimated γ coefficients for equation (11) are -0.28 and -0.30, with

t-stats of -2.47 and -2.74 respectively. Thus, we find that conditioning the dispersion strategy on implied correlation yields results similar to those of the naive strategy.

B. Delta-hedged Dispersion Trading

The naive dispersion strategy involves positions on near-ATM straddles which have very low delta at the time the positions are opened. Therefore, initially, the delta exposure of the dispersion trades are very low. However, as the prices of the underlying stocks change, the deltas of the straddle positions will also change, leading to higher exposure to delta risk. For individual stock options, delta risk could be hedged with the underlying stock. For index options, since index is a weighted average of its component stocks, their delta exposure can also be hedged using its component stocks. We conduct the dispersion trading strategy the same as before except that the delta-exposure is hedged daily using the S&P 500 components stocks. Specifically, the long leg of the dispersion trade has a delta exposure to stock i as:

$$\Delta_{i,t}^{long} = \Delta_{i,t}^{Call} + \Delta_{i,t}^{Put}, \tag{16}$$

where $\Delta_{i,t}^{Call}$ and $\Delta_{i,t}^{Put}$ are the Black-Scholes deltas of stock i at time t respectively.The short leg has a delta exposure to stock i as:

$$\Delta_{i,t}^{short} = n_{i,t}(\Delta_{I,t}^{Call} + \Delta_{I,t}^{Put}), \tag{17}$$

where $\Delta_{I,t}^{Call}$ and $\Delta_{I,t}^{Put}$ are the Black-Scholes deltas of S&P500 index at time t respectively. We compute the Black-Sholes delta at the close of trading each day between the investment date and the expiration date using closing stock prices and index level, the time to expiration, and the dividends paid during the remaining life of the option. The volatility rate is the annualized sample volatility using daily log returns over the prior 22 trading days and the interest rate is the continuously compounded one-month LIBOR rate at the time the position is opened.

Therefore, the dispersion position's delta exposure to stock i is

$$\Delta_{i,t}^{all} = \Delta_{i,t}^{long} - \Delta_{i,t}^{short}. \tag{18}$$

We hedge this risk at the investment date by selling $\Delta_{i,t}^{all}$ units of stock i at closing price. Each day during the life of the trade, we rebalance the delta-position so that the trade keeps delta-neutral until the expiration date. The return of the daily delta-hedged dispersion strategy is

$$\frac{V_T - V_t - \sum_{s=t}^{T-1} \sum_{i=1}^{N} n_{i,s} \Delta_{i,s}^{all} (S_{i,s+1} + D_{i,s} - S_{i,s}) e^{r(T-s)}}{V_t - \sum_{i=1}^{N} n_{i,t} \Delta_{i,t}^{all} (S_{i,t} - e^{r(T-t)})}. \tag{19}$$

The return after transaction costs is defined in the similar fashion as equation (7).

Panel C of Table 5 summarizes the returns of the delta-hedged dispersion strategy. With delta exposures of the portfolio daily-rehedged using the 500 component stocks, the average return increases from 10.7% for the naive strategy to 15.2% now. The standard deviation of strategy decreases from 0.628 to 0.592, and the Sharpe ratio goes up from 0.59 to 0.89. Estimated intercepts from regressions of equation (8) and equation (9) both rise to 0.16. Hence, delta-hedging can make dispersion strategy perform better by increasing the average returns without incurring more risk.[4] Looking at the performance over the pre-2000 and post-2000 periods, we find that the pre-2000 return increases from 24% to 27.5% and post-2000 rises from −2.6% to 3.2%. Similarly, both Sharpe ratios and alphas for the two subperiods are enhanced over those for the naive dispersion strategy. However, tests of changing profitability presented in Table 6 supports the hypothesis that the performance of the daily-delta hedged dispersion strategy decrease significantly from 1996–2000 to 2001–2005. The γ is -0.29 and t-stat is 2.28, which are both significant at 5% level.

[4] Transaction costs of trading stocks are not taken into account here, which might be significant.

C. Using a subset of the component stocks

The next step to improve the strategy is to pick the best component stocks to buy straddles on. Table I have shown that transaction costs are substantial in options market. By selecting a subset of the component stock options to execute the dispersion trades, we are actually reducing the transaction costs involved in the strategy and thus might increase the return after transaction costs. Our selection method follows the procedure in Su (2005), which selects the optimal subset of component stocks using Principal Component Analysis (PCA). PCA is one of the popular data mining tools to reduce the dimensions in multivariate data by choosing the most effective orthogonal factors to explain the original multivariate variables. Specifically, stock selection is completed in three steps as follows:

Step 1 On each investment date, find the covariance matrix using the historical returns of all component stocks as below

$$\begin{bmatrix} \omega_{1,t}^2\sigma_{1,t}^2 & \omega_{1,t}\omega_{2,t}\sigma_{1,t}\sigma_{2,t}\rho_{12,t} & \cdots & \omega_{1,t}\omega_{N,t}\sigma_{1,t}\sigma_{N,t}\rho_{1N,t} \\ \omega_{1,t}\omega_{2,t}\sigma_{1,t}\sigma_{2,t}\rho_{12,t} & \omega_{2,t}^2\sigma_{2,t}^2 & \cdots & \omega_{2,t}\omega_{N,t}\sigma_{2,t}\sigma_{N,t}\rho_{2N,t} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_{1,t}\omega_{N,t}\sigma_{1,t}\sigma_{N,t}\rho_{1N,t} & \omega_{2,t}\omega_{N,t}\sigma_{2,t}\sigma_{N,t}\rho_{2N,t} & \cdots & \omega_{N,t}^2\sigma_{N,t}^2 \end{bmatrix}$$

where $\sigma_{i,t}$ and $\rho_{ij,t}$ are the realized standard deviation of return of stock i and the realized correlation between returns of stock i and stock$j$, calculated over the one year period prior to the investment date t, and $\omega_{i,t}$ is the index weights of stock i at investment date t.

Step 2 Decompose the covariance matrix into the eigenvalue vector ordered by importance and the corresponding eigenvectors. Choose the first n principal components such that the cumulative proportion of the explained variance is above 90%.

Step 3 Select the subset of 100 stocks which have the highest cumulative correlation with the principal components chosen in step 2.

After the subset of stocks is selected, we implement the original dispersion strategy by buying the index straddles and selling individual straddles on this 100 stocks.

Panel D of Table 5 displays the trading results. We find that the average return of the strategy increases from 10.7% per month to 29.5% per month and is significantly positive with a t-statistic of 2.19. Because the standard deviation also increases to 1.48, the resulting Sharpe ratio rises only to 0.69. In addition, α increases to 0.28 and is statistically significant at 5% level. When we examine the performance of the subsetting strategy in the two subperiods of 1996–2000 and 2001–2005, we find similar results as previous adjusted dispersion strategies. The average return is 51.1% and statistically significant prior to 2001 and then drops to 8% and insignificant after 2001. The Sharpe ratio decreases from 1.05 to 0.23. And the estimated intercepts for equation (8) and equation (9) both decreases from 0.58 to 0.04 and 0.52 to -0.18 respectively. Table 6 presents the test results for a structural change at the end of 2000. We find a marginally significant t-statistic and significant γ coefficients for equation (10) and equation (11). Hence, the subsetting dispersion strategy yields the same results as other strategies–the profits disappear over the 2001-2005 subperiod.

D. Trading Index Strangles and Individual Straddles

Finally, we make the last attempt to enhance the performance of the primitive dispersion strategy. Previous studies have shown that out-of-the-money put options yields are priced highest among different index option series. See, for example, Bollen and Whaley (2004), who shows that a delta-hedged trading strategy that sells S&P 500 index options is most profitable for selling out-of-the-money put index options. In addition, at-the-money individual call options are priced relatively lower than other individual option series. So, we still stick to near-ATM individual straddles on the long side of the strategy.

We expect that a strategy that longs individual at-the-money straddles and shorts index out-of-the-money can produce a higher return than a dispersion strategy that trades at-the-money straddles for both index and index component stocks.

The general setup is the same as previous strategies, except that out-of-the-money index options are selected instead to trade against individual at-the-money straddles. We select out-of-the-money index options as follows: first, we restrict the sample of index options such that $1.05 <= K/S < 1.1$ for call options and $0.90 < K/S <= 0.95$ for put options, where S is the index value at investment date, K is the option strike price; then, we select options with strike prices closest to 1) $1.05S$ for call options and 2) $0.95S$ for put options.

Panel E of Table 5 shows that this strategy produces a mean return of 10%. As predicted, this strategy turns out to be much more profitable than the primitive dispersion strategy that sells at-the-money index straddles. Although the average return is not higher than that of the simplest trading strategy, we find that this strategy has a much smaller standard deviation of 0.392 compared to 0.628 for the primitive strategy. Thus, it yields a more significant t-statistic of 2.81. The Sharpe ratio is 0.89, much higher than that of the simplest strategy (0.58). Moreover, we find the α of the strategy is 0.08 and significantly positive with a t-statistic of 2.41. Consistent with previous results, this strategy is more profitable over the subperiod 1996-2000 than the subperiod 2001-2005. We find the mean monthly return decreases from a strongly significant 19.4% to a non-significant 0.7%. Similarly, the Sharpe ratio drops from 2 to 0.05, and α's go down from 0.21 to -0.01 and from 0.17 to -0.13 respectively for equation (8) and equation (9). Again, both dummy regressions and t-tests presented in Table 6 support the conclusion that the profitability of the strategy decreases significantly around 2000.

Therefore, all of the adjusted strategies studies accomplish the task of beating the performance of the primitive dispersion strategy. And the daily-delta-hedged dispersion strategy and the one that sells OTM index strangles work best among them. Yet we find all strategies perform significantly worse after 2000. So the changing profitability result we find for the primitive dispersion strategy still holds.

VI. Implications

As noted in Section III, investigating whether the performance of dispersion strategies changes following the structural changes in the options market around 2000 allows us to distinguish between the risk-based hypothesis and the market inefficiency hypothesis. The risk-based hypothesis argues that index options are overpriced versus individual options because correlation risk, which is only present in index options, is negatively priced in equilibrium. The market-inefficiency hypothesis explains the overpricing of index options as the result of the demand pressure effect. The evidence we find in the last section indicates that dispersion strategies become unprofitable after 2000. This is in support of the market inefficiency hypothesis because if the correlation risk premium embedded in the index options is a fundamental market factor then it should not be affected by market structural changes, unless the correlation between changes in stock return correlations and the stochastic discount factor happens to change too around 2000.

After the bursting of the internet bubbles starting from March 2000, it is possible that changes in correlation are more predictable after 2000. This makes the forecast risk of correlation lower during the post-2000 period and could possible explain the reduced profitability of dispersion strategies after 2000. To address this concern, we want to test whether the forecast risk of realized correlation changed significantly around 2000. Here, forecast risks are measured as the variance of forecast errors. To do this, I assume that the forecast errors of correlation $e_{t\leq 2000}$ during the pre-2000 period and $e_{t\geq 2001}$ during the post-2000 period follow the following distribution:

$$e_{t\leq 2000} \sim N(\mu_1, \sigma_1^2), \quad (20)$$

$$e_{t \geq 2001} \sim N(\mu_2, \sigma_2^2). \quad (21)$$

The null hypothesis is

$$H_0 : \sigma_1^2 = \sigma_2^2, \quad (22)$$

while the alternative hypothesis is

$$H_a : \sigma_1^2 > \sigma_2^2. \quad (23)$$

Table 7 presents the means and standard deviations of two different measures of the forecast errors. The first measure is $IC_t - RC_t$, the difference between implied correlation and realized correlation. The second is $GC_t - RC_t$, the difference between GARCH-forecasted correlation and realized correlation. The first measure $IC_t - RC_t$ has a mean of 0.096 over the subperiod 1996–2000 and 0.051 over the subperiod 2001–2005. A test of difference in means confirms that the decrease in the difference between IC_t and RC_t is statistically significant. This is consistent with the diminishing profitability of dispersion strategies we find in Section IV and Section V. Figure 2 plots the implied correlation versus the realized average correlation over our sample period. Indeed, the mean difference between implied correlation and realized correlation has diminished over time since 2001. The second measure does not change significantly from before and after 2000. This is not surprising, as there is no reason to expect GARCH models to perform better because of changes to market environment.

Next, we examine the standard deviations of the two measures of the forecast errors. We find that the standard deviation for the first measure does not differ much over the two subperiods, being 0.113 and 0.094 respectively. And a test of equal variances cannot reject the null hypothesis H_0. Similarly, for the second measure, $GC_t - RC_t$, the standard deviation is 0.107 first and then 0.093. And the F-test statistic of equal variance is insignificant as well. These findings do not support the hypothesis that forecast risk of correlation has reduced a lot since 2001. Thus there is no evidence that profits to dispersion strategies disappear because of the reduced forecast risk.

In fact, practitioners seem to have reached a consensus that the profitability of dispersion trading has diminished over time, especially after 2000. For example, according to Robert Brett, a partner at Brett & Higgins, "It (volatility dispersion strategy) is also a strategy that, through market efficiency and the sophistication of the participants, has been 'arbed' to death, leaving only marginal profit potential."[5] Andy Webb, at Egar Technology, said that, "Under the relatively benign conditions that prevailed up until the summer of 2000, dispersion trading was a reliable money-maker that didn't require much in the way of sophisticated modelling."[6] The improvement of options market efficiency could have led the change of profitability of dispersion trading strategy. Figure 3 plots the implied correlation of DOWJONES industrial average versus the realized average correlation on every Wednesday from October, 1997 till December, 2005.[7] Similar to SPX, the difference between DJX 's implied correlation and realized correlation has diminished over time, especially after 2000. This confirms that the eroded profitability of dispersion strategy is not specific to SPX and might happen to other indices as well. Multiple listings and introduction of ISE have made options cheaper to trade than before and more money have flowed into the options market. In addition, the availability of OptionMetrics and software support of Egartech around 2000 have given people the chance to trade away remaining arbitrage opportunities of dispersion strategy. The reduced performance of dispersion strategies suggests the profits to dispersion trading don't result from priced correlation risk. Therefore, our results are in support of the market inefficiency hypothesis by Bollen and Whaley (2004) and Garleanu, Pedersen and Poteshman (2005).

[5]Smith, Steven, "Using Dispersion: A High Concept at a Low Cost", TheStreet.com, July, 2003.
[6]"Dispersion of Risk", FOW, December 2001.
[7]DJX starts trading options from September, 24, 1997

VII. Conclusion

A number of studies have tried to explain the relative expensiveness of index options and the different properties that index option and individual option prices display. The two hypotheses that are prevalent is that 1) index options bear a risk premium lacking from individual options, and 2) option market demand and supply drive the option prices from their Black-Sholes values. Institutional changes in the option market in late 1999 and 2000, including cross-listing of options, the launch of the International Securities Exchange, a Justice Department investigation and settlement, and a marked reduction in bid-offer spreads, provide a "natural experiment" that allows one to distinguish between these hypotheses. Specifically, these changes in the market environment reduced the costs of arbitraging any differential pricing of individual equity and index options via dispersion trading. If the profitability of dispersion trading is due to miss-pricing of index options relative to individual equity options, one would expect the profitability of dispersion trading to be much reduced after 2000. In contrast, if the dispersion trading is compensation for bearing correlation risk, the change in the option market structure should not affect the profitability of this strategy. In this study, we show that the primitive dispersion strategy, as well as several improved dispersion strategies that revise the primitive dispersion strategies by conditioning,delta-hedging, subsetting, using index out-of-the-money strangles, are much more profitable before 2000 and then become unprofitable. This provides evidence that risk-based stories cannot fully explain the differential pricing anomaly. Future work on how implied volatilities of index options and individual options behave after the structural change might help us understand the specific source for the loss of profitability of dispersion strategies.

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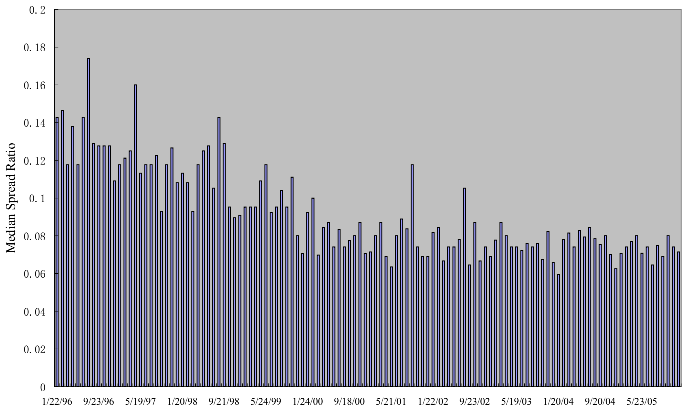
Figure 1. Median Bid-ask Spread Ratios for Call Options and Put Options from 1996 to 2005

Panel A displays the median bid-ask spread ratios, measured as bid-ask spreads over bid-ask midpoints, of our sample call options from 1996 to 2005. Panel B shows the median bid-ask spread ratios for put options.

Panel A: Median Spread Ratios for Call options



Panel B: Median Spread Ratios for Put options

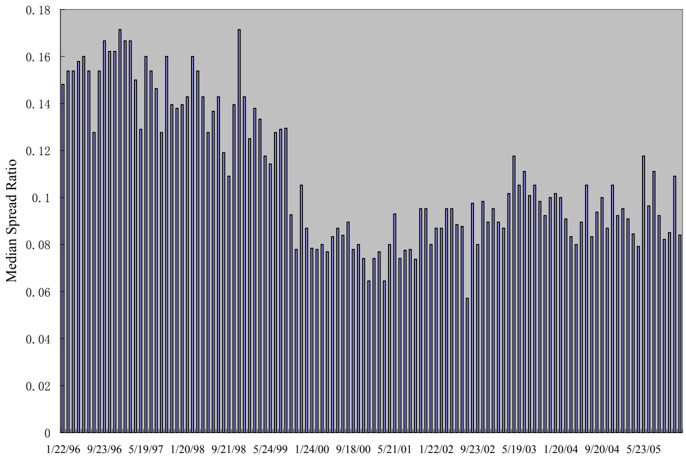


Figure 2. Implied Correlation versus Realized Correlation for S&P500 Index

We plot the implied correlation versus realized correlation on every Wednesday from January,1996 till December 2005. The implied correlation and realized correlation are calculated by plugging implied volatilities and realized volatilities of index options and individual options into equation (3) respectively.

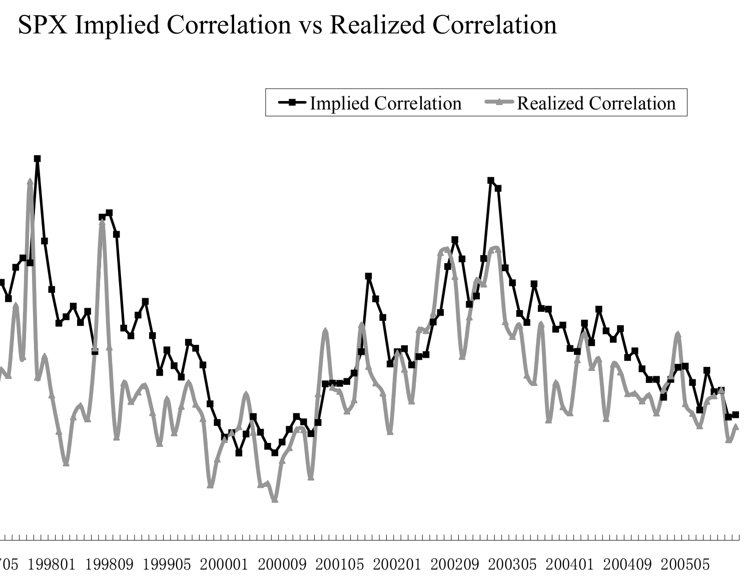


Figure 3. Implied Correlation versus Realized Correlation for Dow Jones Industrial Average Index

We plot the implied correlation versus realized correlation for DJX on every Wednesday from October,1997 till December 2005. The implied correlation and realized correlation are calculated by plugging implied volatilities and realized volatilities of DJX index options and individual options into equation (3) respectively.

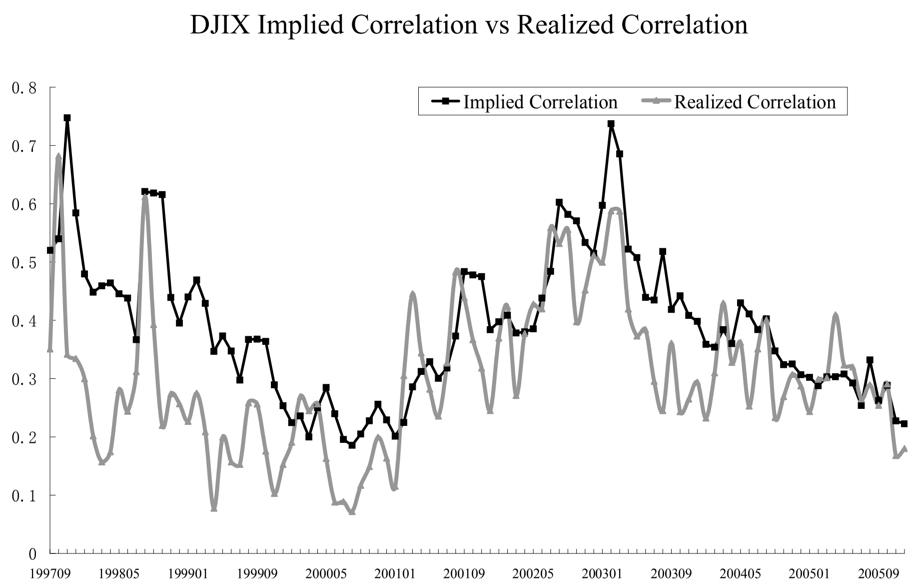


Table 1
Summary Information for Options in Sample, January 1996 – December 2005

This table includes summary information of SPX index options and individual equity options of SPX component stocks, by 5 moneyness categories, on the 144 investments dates from January,1996 to December, 2005. Moneyness categories are defined based on K/S where K is the strike price and S is the stock/index price.

Panel A. SPX Index Options					
Moneyness	Categories	Open Interest	Volume	Quote	Spread
	0.85–0.90	1123.45	70.88	6.765	5.87%
	0.90–0.95	1604.65	129.14	4.580	7.55%
Call	0.95–1.00	2415.46	340.52	2.739	10.43%
Options	1.00–1.05	2809.21	544.31	1.394	19.76%
	1.05–1.10	2610.38	421.41	0.736	38.80%
	1.10–1.15	2606.83	325.66	0.522	52.03%
	0.85–0.90	1753.84	157.05	0.472	55.02%
	0.90–0.95	1772.15	214.59	0.707	40.86%
Put	0.95–1.00	1828.33	313.60	1.335	20.61%
Options	1.00–1.05	1375.65	199.04	2.589	11.06%
	1.05–1.10	914.30	80.17	4.359	7.82%
	1.10–1.15	729.38	44.02	6.174	6.22%
Median		1618.57	195.74	4.610	6.78%
Panel B. Equity Options on SPX Components					
Moneyness	Categories	Open Interest	Volume	Quote	Spread
	0.85–0.90	2786.53	29.50	136.34	1.40%
	0.90–0.95	3898.46	66.34	85.75	2.22%
Call	0.95–1.00	7637.78	538.53	40.77	4.66%
Options	1.00–1.05	9903.86	1625.95	11.66	11.02%
	1.05–1.10	10024.34	1619.68	2.49	38.20%
	1.10–1.15	7408.05	519.72	0.71	71.68%
	0.85–0.90	13574.17	1311.00	1.98	30.07%
	0.90–0.95	14480.91	2645.65	4.26	17.62%
Put	0.95–1.00	12130.68	1926.13	12.44	9.30%
Options	1.00–1.05	6302.45	750.46	35.39	5.26%
	1.05–1.10	3254.67	109.24	77.28	2.72%
	1.10–1.15	2899.13	67.19	124.43	1.81%
Median		8205.49	980.52	54.83	9.52%

Table 2
Test of Changing Bid-Ask Spread

This table reports the results of testing for a difference in the bid-ask spreads between 1996–2000 and 2001–2005. The top 100 largest stocks that are included in S&P 500 over the whole sample period are selected. On each investment date, we first take an average of bid-ask spreads for all the call options with the same underlying stock. We then average the results over the 100 stocks and test whether this value before 2001 is different from that after 2001. The same test is implemented with put options.

	Median Bid-ask Spread		Test	
Options Type	1996–2000	2001–2005	Statistic	p-value
Call	0.109	0.076	10.10	< 0.0001
Put	0.128	0.091	8.46	< 0.0001

Table 3

Returns of the Naive Dispersion Trading Strategy under Different Scenarios

This table reports the average monthly returns, standard deviation, t-stats, annualized Sharpe ratio, p-value of test of normality, regression coefficients (with t-stats in braces) of equation (8) (denoted as α^A, and β^A) and equation (9) (denoted as α^A, and β^A) for the naive dispersion trading strategy under different scenarios, as discussed in Section IV. Panel A shows the results for the naive dispersion strategy. Panel B shows the results for the naive dispersion strategy adjusted for early-exercise premium. Panel C shows the results for the naive dispersion strategy over two different subperiods, using September, 1999 as the breakpoint. Panel D shows the results for the naive dispersion strategy over two different subperiods, using January, 1999 as the breakpoint.

Panel A: The Naive Dispersion Trading Strategy										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.107	0.628	1.87	0.59	0.94	0.11(1.92)	−1.40(−1.23)	0.03(0.49)	−2.94(−2.26)	−0.057(−2.32)
1996–2000	0.240	0.694	2.68	1.20	0.92	0.29(3.29)	−4.71(−1.72)	0.20(2.14)	−7.07(−3.09)	−0.075(−2.28)
2001–2005	−0.026	0.528	−0.37	−0.17	0.95	−0.04(−0.62)	0.68 (0.54)	−0.12(−1.47)	−0.60(−0.41)	−0.052(−1.61)
Panel B: The Naive Dispersion Trading Strategy Adjusted for Early-Exercise-Premium										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.115	0.634	1.99	0.63	0.94	0.13(2.15)	−1.40(−1.21)	0.05(0.72)	−2.91(−2.21)	−0.06(−2.26)
1996–2000	0.247	0.701	2.73	1.22	0.91	0.30(3.34)	−4.75(−1.74)	0.21(2.18)	−7.14(−3.19)	−0.08(−2.28)
2001–2005	−0.017	0.532	−0.25	−0.11	0.95	−0.02(−0.29)	0.73 (0.57)	−0.09(−1.08)	−0.42(−0.28)	−0.05(−1.42)
Panel C: Breakpoint September 1999										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
01/1996–09/1999	0.268	0.768	2.34	1.21	0.92	0.33(2.91)	−2.87(−1.15)	0.22(1.90)	−5.37(−2.72)	−0.07(−2.30)
10/1999–12/2005	0.011	0.508	0.73	0.07	0.97	-0.00(-0.00)	0.03 (0.03)	−0.07(−0.98)	−1.05(−0.83)	−0.05(−1.68)
Panel D: Breakpoint January 2002										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
01/1996–01/2002	0.177	0.681	2.22	0.90	0.93	0.19(2.31)	−1.48(−0.96)	0.12(1.25)	−2.85(−1.60)	−0.05(−1.47)
02/2002–12/2005	−0.001	0.524	−0.02	−0.01	0.95	−0.01(−0.11)	−1.04(−0.64)	−0.11(−1.22)	−2.88(−1.58)	−0.09(−2.03)

Table 4

Test of Changing Profitability of the Naive Dispersion Strategy under Different Scenarios

This table reports the results of testing for a change in the profitability of the naive dispersion trading strategies at the end of 2000. Panel A reports the results of a simple t-test of difference in the mean returns of the strategy described in the leftmost column over the two subperiods 1996–2000 and 2001–2005. Panel B reports the estimates γ coefficient, t-stat, and p-value for equation (10). Similarly, Panel C reports the estimates γ coefficient, t-stat, and p-value for equation (11).

Panel A: Test of difference in means			
Scenario Description	Mean Difference	t-stat	p-value
Dispersion strategy	−0.27	−2.36	0.010
Adjusted for early exercise premium	−0.26	−2.32	0.011
Breakpoint September/1999	−0.26	−2.20	0.015
Breakpoint January/2002	−0.18	−1.61	0.055
Panel B: Regression controlling for market risk			
Strategy Description	γ	t-stat	p-value
Dispersion strategy	−0.28	−2.51	0.015
Adjusted for early exercise premium	−0.27	−2.42	0.017
Breakpoint September/1999	−0.27	−2.29	0.024
Breakpoint January/2002	−0.18	−1.78	0.078
Panel C: Regression controlling for market risk and variance risk			
Strategy Description	γ	t-stat	p-value
Dispersion strategy	−0.31	−2.83	0.006
Adjusted for early exercise premium	−0.29	−2.63	0.096
Breakpoint September/1999	−0.28	−2.48	0.015
Breakpoint January/2002	−0.17	−1.44	0.154

Table 5

Returns of Improved Dispersion Trading Strategies

This table summarizes the returns of revised dispersion trading strategies for 1) the conditional dispersion strategy based on the comparison between implied correlation and historical correlation, 2) the conditional dispersion strategy based on the comparison between implied correlation and Garch-forecasted correlation, 3) Daily-delta-hedged dispersion strategy, 4) Subsetting dispersion strategy based on Principal Component Analysis, 5) Dispersion strategy using OTM index strangles.

Panel A: Based on Implied Correlation and Historical Correlation										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.127	0.624	2.23	0.70	0.94	0.14(2.45)	−1.78(−1.57)	0.04(0.53)	−3.71(−2.91)	-0.07(−3.00)
1996–2000	0.235	0.695	2.62	1.17	0.92	0.28(3.16)	−4.37(−1.63)	0.19(1.99)	−6.84(−2.86)	-0.08(−2.37)
2001–2005	0.019	0.528	0.28	0.12	0.96	0.02(0.28)	−0.12(−0.09)	−0.12(−1.44)	−2.10(−1.46)	−0.08(−2.52)
Panel B: Based on Implied Correlation and Garch-forecasted Correlation										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.140	0.621	2.48	0.79	0.94	0.15(2.70)	−1.74(−1.54)	0.09(1.38)	−2.86(−2.20)	−0.04(−1.68)
1996–2000	0.271	0.682	3.08	1.38	0.92	0.32(3.73)	−4.82(−1.78)	0.26(2.81)	−6.34(−3.03)	−0.05(−1.46)
2001–2005	0.011	0.528	0.16	0.12	0.96	0.01(0.15)	0.19(0.15)	−0.08(−0.98)	−1.10(−0.74)	−0.05(−1.56)
Panel C: Delta-hedged Dispersion Strategy										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.152	0.592	2.81	0.89	0.75	0.16(2.84)	−0.70(−0.64)	0.16(2.46)	−0.65(−0.51)	0.002(0.07)
1996–2000	0.275	0.548	3.86	1.74	0.67	0.30(4.18)	−2.46(−1.61)	0.31(3.80)	−2.36(−1.33)	0.003(0.11)
2001–2005	0.032	0.613	0.40	0.18	0.76	0.03(0.35)	0.27 (0.18)	0.01(0.06)	−0.08(−0.04)	−0.01(−0.36)
Panel D: Dispersion Strategy based on PCA										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.295	1.479	2.19	0.69	0.90	0.28(2.08)	-0.77(-0.28)	0.15(0.97)	-2.34(-1.07)	-0.09(-1.62)
1996–2000	0.511	1.690	2.34	1.05	0.87	0.58(3.14)	-6.53(-1.83)	0.52(2.27)	-10.53(-2.45)	-0.07(-1.46)
2001–2005	0.080	1.209	0.51	0.23	0.95	0.04(0.25)	1.49(0.86)	−0.18(−1.02)	0.60(1.67)	−0.15(−1.81)
Panel E: Trading OTM index Strangles										
Sample Period	Mean	Std.Dev	t	Sharpe Ratio	Test of Normality	α^A(t-stat)	β^A(t-stat)	α^B(t-stat)	β^B(t-stat)	θ(t-stat)
All	0.100	0.392	2.81	0.89	0.81	0.08(2.41)	1.77(1.83)	0.03(0.74)	1.18(1.51)	−0.04(−2.71)
1996–2000	0.194	0.336	4.48	2.00	0.76	0.21(4.65)	−1.12(−1.19)	0.17(3.56)	−2.06(−1.93)	−0.03(−1.76)
2001–2005	0.007	0.423	0.12	0.05	0.90	−0.01(−0.25)	2.90(2.35)	−0.13(−2.41)	1.94(1.01)	−0.07(−3.63)

Table 6

Test of Changing Profitability of Improved Dispersion Trading Strategies

This table reports the results of testing for a change in the profitability around 2000 for the following revised dispersion trading strategies: 1) the conditional dispersion strategy based on the comparison between implied correlation and historical correlation, 2) the conditional dispersion strategy based on the comparison between implied correlation and GARCH-forecasted correlation, 3) Daily-delta-hedged dispersion strategy, 4) Subsetting dispersion strategy based on Principal Component Analysis, 5) Dispersion strategy using OTM index strangles. The tests are t-tests of mean differences, and dummy regressions are based on equation (10) and equation (11).

Panel A: Test of difference in means			
Strategy Description	Mean Difference	t-stat	p-value
Conditioning based on implied correlation vs historical correlation	−0.22	−1.92	0.029
Conditioning based on implied correlation vs GARCH-forecasted correlation	−0.27	−2.33	0.011
Daily delta-hedged dispersion strategy	−0.24	−2.28	0.004
Subsetting based on PCA	−0.43	−1.78	0.037
Trading OTM index strangles	−0.19	−2.69	0.004
Panel B: Regression controlling for market risk			
Strategy Description	γ	t-stat	p-value
Conditioning based on implied correlation vs historical correlation	−0.23	−2.04	0.044
Conditioning based on implied correlation vs GARCH-forecasted correlation	−0.27	−2.47	0.015
Daily delta-hedged dispersion strategy	−0.29	−2.18	0.031
Subsetting based on PCA	−0.44	−2.08	0.040
Trading OTM index strangles	−0.17	−2.58	0.011
Panel C: Regression controlling for market risk and variance risk			
Strategy Description	γ	t-stat	p-value
Conditioning based on implied correlation vs historical correlation	−0.28	−2.47	0.015
Conditioning based on implied correlation vs GARCH-forecasted correlation	−0.30	−2.74	0.007
Daily delta-hedged dispersion strategy	−0.25	−2.36	0.022
Subsetting based on PCA	−0.51	−2.29	0.024
Trading OTM index strangles	−0.18	−2.86	0.005

Table 7
Test of Changing Forecast Risk

This table reports the results of testing for a change in the distribution of the forecast errors of correlation. Forecast errors before and after 2000 are assumed to follow the normal distributions: $e_{t \leq 2000} \sim N(\mu_1, \sigma_1^2)$ and $e_{t \geq 2001} \sim N(\mu_2, \sigma_2^2)$. Test of equal means ($t$-test) and equal variances (F-test) are presented. For the variance test, the null hypothesis is $H_0 : \sigma_1^2 = \sigma_2^2$, and the alternative hypothesis is $H_a : \sigma_1^2 > \sigma_2^2$. The two measures of forecast errors are 1) IC−RC, implied correlation minus realized correlation, 2) GC−RC, GARCH-forecasted correlation minus realized correlation.

Proxy for Forecast Errors	Sample Period	Mean of Forecast Errors	Test of Equal Means of Forecast Errors	Std.Dev of Forecast Errors	Test of Equal Variance of Forecast Errors
IC−RC	1996–2000	0.096	t-stat=2.57	0.113	F-stat=1.45
	2001–2005	0.051	p-value=0.01	0.094	p-value=0.16
GC−RC	1996–2000	0.026	t-stat=1.07	0.107	F-stat=1.32
	2001–2005	0.015	p-value=0.28	0.093	p-value=0.29