# **ARBITRAGE OPPORTUNITIES IN THE**

# **ETF MARKET**

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## I. ABSTRACT

Over the past decade, Exchange Traded Funds (or ETFs) have been widely used to replicate the performance of a number of indices. This paper investigates the efficiency of the market for DIAMONDs, an ETF which is based on the DOW Jones Industrial Average. We first considered the composition of DIAMONDs and mechanics involved with arbitrage strategies. Then, we attempted to develop trading strategies based on traditional linear regression statistical models, which showed little predictive power and indicated the market for DIAMONDs was considerably efficient. Finally, we utilized a sophisticated mathematical model, Artificial Neural Networks that better captured the dynamics of mispricings in the market for DIAMONDs.

## **II. INTRODUCTION**

Financial innovation has created many interesting and powerful new products for investors to use in their quest to maximize returns. For every product created, opportunities are also created and quickly exploited by savvy traders. Exchange Traded Funds (ETFs) have emerged over the past few years and have quickly become an important investment tool for most participants in today's financial markets.

ETFs are passive index funds that allow investors to trade a portfolio of securities in a single transaction. Since ETFs are one step removed from the actual shares of the index, arbitrage is used by the market to maintain a close relationship between the net asset value of the ETF and the corresponding index. However, supply and demand forces are constantly at work in this relationship and potential opportunities may exist for an arbitrageur to profit from any differences.

This paper will explore the many components of ETFs in general and DIAMONDs in particular. We will analyze various trading strategies and explain the forces that may create arbitrage opportunities. We will also apply new methodologies from science in order to predict arbitrage opportunities.

A successful financial forecasting system should be able to find and exploit inefficiencies in a market. In contrast to the traditional Efficient Market Hypothesis, there is an overwhelming evidence that arbitrage opportunities exist in a given period of time<sup>1,2</sup>. Hedge funds make money by taking positions in market areas where prices are not set efficiently<sup>3</sup>. A good trading strategy that is based on a forecasting model must be applied unemotionally and consistently. Whenever irrational mental model biases enters into the trading system money can be lost. Any trading strategy will sometimes make money, and at other times loose money for a trader. The purpose of a superior forecasting model is to minimize losses. The goal of this paper is to study an ETF arbitrage mechanism, and to develop a forecasting system that could allow traders to engage in arbitrage opportunities in the DIAMONDs market.

<sup>&</sup>lt;sup>1</sup> Market Wizards, Schwager, 1992 <sup>2</sup> A Stock Operator, Lefevre, 1985

<sup>&</sup>lt;sup>3</sup> "Hedge Fund Boom Brings Challenges," Financial Times, June 7<sup>th</sup> 2004.

## **III. OVERVIEW OF EXCHANGE TRADED FUNDS**

## **Exchange-Traded Funds (ETFs)**

Exchange-traded funds (ETF) are registered investment companies under the Investment Company Act of 1940, which have received certain exceptive relief from the SEC to allow secondary market trading in the ETF shares. ETFs are index-based products, in that each ETF represents a portfolio of securities that is intended to provide investment results that, before fees and expenses, generally correspond to the price and yield performance of the underlying benchmark index<sup>4</sup>.

Each ETF represents a basket of securities that is designed to generally track an index whether the index is based on stocks, bonds, industry sector, or international markets yet ETFs trade like a single stock<sup>5</sup>. ETFs offer several benefits compared to mutual funds:

- ETFs trade intraday rather than at closing prices, which is increasingly valuable in the presence of volatility.
- ETFs can be purchased on margin.
- ETF trading costs are generally lower than those for the underlying stocks.
- ETFs provide unique tax advantages. Since they could be redeemed in-kind, as opposed to cash, shareholder redemptions do not create tax events for the fund.
- ETFs can be sold short without an uptick<sup>6</sup>.

<sup>&</sup>lt;sup>4</sup> www.amex.com

<sup>&</sup>lt;sup>5</sup> www.amex.com

<sup>&</sup>lt;sup>6</sup> Joanne M. Hill and Barbara Mueller, "The Appeal of ETFs", Fall 2001.

Most ETFs are Unit Investment Trusts (UITs). UITs are investment companies that purchase a fixed, unmanaged portfolio of securities and then sell large blocks of shares in the trust to investors. The large blocks of shares are called creation units. The creation unit size can vary by fund and ranges from 25,000 to 600,000 shares. Institutional investors, specialists and market makers engage in the creation and redemption of creation units and typically are charged a creation or redemption fee that varies from fund to fund. The fees for creations and redemptions can be found in the prospectus of each ETF.

## **Applications of ETFs<sup>7</sup>**

ETFs appeal to both institutional and individual investors. The following are some common applications of ETFs:

- Equitizing cash: Investors with idle cash in their portfolios can invest their money in a product tied to the fund's benchmark or to their favorite stocks. This could be a temporary investment that minimizes drag on cash or benchmark risk while the investor decides which stocks to buy or waits until a stock reaches the price targeted for a purchase.
- Managing cash flows: If a fund needs to raise cash quickly to meet redemptions, the manager can liquidate holdings of ETFs tied to the fund's benchmark. This buys the manager time to select which holdings to sell, possibly allowing a more orderly liquidation of the positions.

<sup>&</sup>lt;sup>7</sup> Joanne M. Hill and Barbara Mueller, "The Appeal of ETFs", Fall 2001.

- Diversifying sector exposure: Investing in shares tied to an index or base of stocks provided diversified exposure to a volatile sector, reducing risk in the event of shakeout. Typically, the volatility of risk associated with an index or basket is lower than the volatility or risk of the individual index components.
- Filing gaps or taking active views on sectors: A fund manager could buy ETFs based on the energy or technology sector to increase exposure to that sector. Such strategies could be used to reduce sector or industry misweightings in a portfolio relative to a benchmark or to implement a temporary tilt to a sector.
- Modifying style exposure: Managers of a portfolio with an S&P 500 value tilt relative to the an S&P 500 benchmark could buy S&P 500 Growth iShares to adjust their portfolio exposure. If a portfolio has a style tilt relative to its benchmark, its style exposure could be adjusted using ETFs based on style indexes.
- Shorting or hedging index exposure: Investors might want to profit from the expectation of a short-term correction in the broad market related to negative economic news. S&P 500 ETFs maybe sold short against long stock holdings in a portfolio as a hedge against a decline in a large-cap stocks, thereby reducing the broad market risk exposure or beta of the portfolio.
- Using completion strategies: A pension fund may want to complete the holdings of external managers who, in aggregate, bring a value tilt to the pension fund equity holding. By including an S&P 500 and Nasdaq-100 ETF in the completion portfolio, the fund has an efficient means of reducing the value tilt and the underweighting relative to the strategic benchmark.

- Using long/ short (market-neutral strategies): An investor has identified attractive stocks for a long portfolio position but cannot identify a sufficient number of stocks to short in the sectors represented. By selling short a sector ETF, the dollar amount of the longs can be balanced with a diversified short portfolio including many stocks in that sector.
- Managing concentrated portfolios more efficiently: A portfolio has a concentrated holding in a stock expected to decline in price, but cannot sell the holding because of potential market impact, undesirable tax consequences, or other restrictions on the position. Shorting ETFs in related sectors or industries as a temporary hedge can be less costly because of the greater liquidity and lower volatility of the diversified ETF product.
- Gaining diversified exposure to foreign markets: An investor needs to fill a country gap in the international holdings or has a positive country view but cannot identify specific stock to buy. For non-US investors, ETFs tied to a US equity index may be an easy way to increase exposure to US equities. The same goes for US investors seeking exposure to some of the non-US equity markets.

## Largest ETFs Traded on the American Stock Exchange and Their Return History<sup>8</sup>

The American Stock Exchange was the pioneer in the creation of ETFs and remains the center of development and the global market leader with more than 120 listed ETFs. The following table lists many of the most common ETFs and their returns for one, three, five and ten years:

<sup>8</sup> www.amex.com

			As of	As of Quarter Ending 03/31/2004			
Product .	<u>Symbol</u>	<u>1 Yr</u>	<u>3 Yr</u>	<u>5 Yr</u>	<u>10 Yr</u>	<u>Since</u> Inception	
DIAMONDS	DIA	32.24	11.93	16.57	NA	50.35	
FORTUNE 500 Index Tracking Stock	FFF	32.89	0.92	NA	NA	-14.06	
iShares DOW Jones US Total Market	IYY	37.44	4.41	NA	NA	-16.33	
iShares GS \$ InvesTopTM Corporate Bond Fund	LQD	8.12	NA	NA	NA	19.02	
iShares Lehman 1-3 Year Treasury Bond Fund	SHY	2.08	NA	NA	NA	5.01	
iShares Lehman 20+ Year Treasury Bond Fund	TLT	5.91	NA	NA	NA	16.95	
iShares Lehman 7-10 Year Treasury Bond Fund	IEF	4.85	NA	NA	NA	13.33	
iShares Lehman Aggregate Bond Fund	AGG	NA	NA	NA	NA	3.83	
iShares Russell 1000	IWB	36.09	3.33	NA	NA	-17.05	
iShares Russell 1000 Growth	IWF	31.87	-5.78	NA	NA	-39.18	
iShares Russell 1000 Value	IWD	40.45	12.81	NA	NA	14.21	
iShares Russell 2000	IWM	63.43	35.31	NA	NA	30.24	
iShares Russell 2000 Growth	IWO	62.76	15.97	NA	NA	-22.25	
iShares Russell 2000 Value	IWN	63.96	54.62	NA	NA	76.35	
iShares Russell 3000	IWV	37.83	5.18	NA	NA	-11.52	
iShares Russell 3000 Growth	IWZ	33.83	-4.48	NA	NA	-43.27	
iShares Russell 3000 Value	IWW	42.01	15.31	NA	NA	19.48	
iShares Russell Midcap Growth Index Fund	IWP	49.25	NA	NA	NA	5.96	
iShares Russell Midcap Index Fund	IWR	50.45	NA	NA	NA	21.73	
iShares Russell Midcap Value Index Fund	IWS	51.14	NA	NA	NA	30.03	
iShares S&P 100 Index Fund	OEF	NA	NA	NA	NA	NA	
iShares S&P 1500 Index Fund	ISI	NA	NA	NA	NA	-0.57	
iShares S&P 500	IVV	34.93	1.61	NA	NA	-18.00	
iShares S&P 500 BARRA Growth	IVW	26.46	0.94	NA	NA	-30.08	
iShares S&P 500 BARRA Value	IVE	43.81	1.28	NA	NA	1.02	
iShares S&P MidCap 400	IJH	48.80	35.00	NA	NA	35.09	
iShares S&P MidCap 400/BARRA Growth	IJK	40.86	23.48	NA	NA	-7.47	
iShares S&P MidCap 400/BARRA Value	IJJ	56.59	46.60	NA	NA	68.16	
iShares S&P SmallCap 600	IJR	56.26	42.84	NA	NA	50.14	
iShares S&P SmallCap 600 BARRA Growth	IJT	50.25	38.91	NA	NA	14.14	
iShares S&P SmallCap 600 BARRA Value	IJS	61.90	44.53	NA	NA	62.06	
MidCap SPDRS	MDY	48.63	34.51	71.39	NA	250.25	
Nasdaq-100 Index Tracking Stock	QQQ	41.19	-8.81	-32.09	NA	-27.38	
PowerShares Dynamic Market Portfolio	PWC	NA	NA	NA	NA	35.99	
PowerShares Dynamic OTC Portfolio	PWO	NA	NA	NA	NA	43.21	
Rydex S&P Equal Weight ETF	RSP	NA	NA	NA	NA	39.99	
SPDRS	SPY	34.82	1.63	-6.29	196.82	213.40	
streetTRACKS DOW Jones Global Titans 50 Index	DGT	30.62	-6.21	NA	NA	-23.97	
streetTRACKS DOW Jones US LargeCap Growth	ELG	28.85	-14.58	NA	NA	-51.29	
streetTRACKS DOW Jones US LargeCap Value	ELV	34.97	6.28	NA	NA	4.27	
streetTRACKS DOW Jones US SmallCap Growth	DSG	60.05	5.43	NA	NA	-30.58	
streetTRACKS DOW Jones US SmallCap Value	DSV	62.28	69.08	NA	NA	93.59	
Vanguard Extended Market VIPERs	VXF	57.28	NA	NA	NA	24.70	
Vanguard Growth VIPERs	VUG	NA	NA	NA	NA	-2.90	
Vanguard Large-Cap VIPERs	VV	NA	NA	NA	NA	-1.18	
Vanguard Mid-Cap VIPERs	VO	NA	NA	NA	NA	0.14	
Vanguard Small-Cap Value VIPERs	VBR	NA	NA	NA	NA	1.76	
Vanguard Total Stock Market VIPERs	VTI	39.67	NA	NA	NA	-3.91	
Vanguard Value VIPERs	VTV	NA	NA	NA	NA	-1.35	

Source: www.amex.com

## ETF Net Asset Value (NAV)

The price of an ETF is expected to closely track its net asset value (NAV). The NAV is equal to:

- The price of the stocks in the underlying index
- Plus the portfolio cash cash on hand held at the Trust
- Plus accrued dividends dividends that the stocks in the underlying index pay are accrued and paid as much as six weeks after the ex-dividend date.
- Minus trust expenses management fees charged by the Trust contribute to differences between the underlying index return and the return on the ETF.

Differences between the price of the ETF and its NAV represent arbitrage opportunities.

## **Arbitrage Opportunities**

Since ETFs trade as shares on an exchange, their price is influenced by supply and demand. In a very active market, ETFs would trade at their NAV, which is their fair market value. However, if demand exceeds supply or vice versa, the ETF share prices would become different from their fair value. The magnitude of the difference between the price of an ETF share and its fair value is closely tied to the ability of the market makers to hedge risk, the method of hedging and the price of the hedging instrument<sup>9</sup>. The factors that make it difficult or more costly to hedge risk for the market maker can cause the ETFs to trade away from their NAV in the short run. Those factors are:

• Reduced liquidity of the futures of the underlying index

<sup>&</sup>lt;sup>9</sup> Joanne M. Hill and Barbara Mueller, "The Appeal of ETFs", Fall 2001.

- Mispricing or any disruption in trading of the futures contract takes place
- Degree to which the trust or fund tracks the underlying index
- Degree to which the market maker's hedge tracks the underlying trust or fund
- Halts or suspensions in index constituent stocks
- Volatility of underlying index
- Presence of other hedging costs (foreign markets)<sup>10</sup>.

## DIAMONDs

To test market efficiency in the DIAMONDs market, we worked with our sponsor to develop a model that would allow us to "paper trade" the DIAMOND by converting a basket of DOW component stocks into creation units and vice versa. We call this a "creation and redemption" trading strategy. If an efficient market exists for the DIAMONDs, no profits should be realized for a trader who converts the DOW stocks into DIAMONDs and DIAMONDs into DOW stocks.

Before describing the mechanics of the trade, it is important to understand the pieces of the ETF puzzle. DIAMOND Creation Units are composed of 50,000 individual DIAMONDs<sup>11</sup>. Creation Units can be created or redeemed only by placing orders with the Distributor and making Portfolio Deposits through one of two different mechanisms:

<sup>&</sup>lt;sup>10</sup> Joanne M. Hill and Barbara Mueller, "The Appeal of ETFs", Fall 2001.

<sup>&</sup>lt;sup>11</sup> DIAMONDs, Trust Series I, Prospectus, February 26, 2004, Page 4

1) DIAMONDS Clearing Process or 2) outside the DIAMONDS Clearing Process by an individual who has executed a Participant Agreement with the Distributor and the Trustee<sup>12</sup>.

The Portfolio Deposit consists of a basket of DOW component stocks and a cash component. The specific number of shares of each stock in the basket is specified by a Portfolio Report provided by the National Securities Clearing Corporation and calculated at "Evaluation Time," which is after the markets close. It is important to obtain this report each day as the composition of the Portfolio Deposit may be adjusted by the Trustee in order to make the NAV of a creation unit and the Portfolio Deposit equal and also to enable the ETF to mirror the DJIA.<sup>13</sup> This document lists the names of the stocks, number of shares of each stock, NAV per index receipt and the total cash amount per creation unit.

The Cash Component of a Portfolio Deposit is made up of the Dividend Equivalent Payment (DEP) and the Balancing Amount. The DEP accounts for dividends paid on the DOW stocks net of expenses and the Balancing Amount makes up the difference in order to equate the creation transaction to the NAV of the Trust on a Creation Unit basis on the transaction date<sup>14</sup>. It is important to remember that DIAMONDS pay dividends on a monthly basis and accrue expenses on a daily basis. The Portfolio Report allows an investor to calibrate a trading model to ensure that these details are factored into a trading analysis. The creation process is illustrated in the following diagram:

<sup>&</sup>lt;sup>12</sup> DIAMONDs, Trust Series I, Prospectus, February 26, 2004, Page 5

<sup>&</sup>lt;sup>13</sup> DIAMONDs, Trust Series I, Prospectus, February 26, 2004, Page 40

<sup>&</sup>lt;sup>14</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 24

## **Creation Process**



## **Quick Creation / Redemption Facts:**

<u>Fee</u><sup>15</sup>: If made through the DIAMONDs Clearing Process Creation / Redemption fee of \$1,000 per day (not per creation / redemption). If outside the DIAMONDs Clearing Process a fee not to exceed \$3,000 may be charged in addition to the \$1,000 transaction fee<sup>16</sup>.

Creation Unit<sup>17</sup>: 50,000 DIAMONDs

<u>Portfolio Deposit<sup>18</sup></u>: Portfolio of DOW securities + Cash Component

<u>Cash Component<sup>19</sup></u>: Dividend Equivalent Payment + Balancing Amount

<u>Dividend Equivalent Payment<sup>20</sup></u>: An amount equal, on a per-Creation Unit basis, to the

dividends on the Portfolio (with ex-dividend dates within the accumulation period), net of

expenses and accrued liabilities for such period.

The NAV of a Creation Unit for Creation/Redemption purposes is calculated at the end of the trading day at Evaluation Time. Creation/Redemption orders that meet all order

<sup>&</sup>lt;sup>15</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 24

<sup>&</sup>lt;sup>16</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 27

<sup>&</sup>lt;sup>17</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 24

<sup>&</sup>lt;sup>18</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 5

<sup>&</sup>lt;sup>19</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 5

<sup>&</sup>lt;sup>20</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 5

criteria as outlined in the DIAMONDs Trust Prospectus will be processed based on this end of day  $NAV^{21}$  According to State Street Bank, there is no way to capture intraday values of the DJIA in the creation/redemption process. For intraday trading of DIAMONDs, the Sponsor reports every fifteen seconds during a trading day the DEP as of the previous day and the value of the securities in a Portfolio Deposit on a DIAMOND basis.

For DIAMONDs, the NAV calculation is based on the closing price of 50,000 DIAMONDs plus or minus an adjustment amount known as Excess Cash. For the DJIA, the NAV calculation is based on the closing index value multiplied by the number of shares of each DOW stock as outlined in the Portfolio Report, plus or minus a cash component. The tables below illustrate NAV calculation as of May 5, 2004 for creation/redemption strategies.

<b>DIAMOND</b> Creation Unit		<b>Creation</b> Unit
Closing price on May 5, 2004	103.46	\$5,173,000.00
NAV Per Index Receipt	103.323498600	
Excess Cash Amount	(0.1365014)	(\$6,825.07)
Shares	50,000	
NAV Per Creation Unit		\$5,166,174.93
DJI		
Closing Price on May 5, 2004	10,310.95	
Divisor	0.14090166	
Shares	3553	
Value of DJI Per DIA Creation Unit		\$5,161,904.89
Cash Component		\$4,269.94
-		\$5,166,174.83

\*\* Creation Unit / DJI off by \$0.10 due to estimation of trading costs.

<sup>&</sup>lt;sup>21</sup> DIAMONDs Trust Series I, Prospectus, February 26, 2004, Page 27

For the purposes of our paper, we studied both intraday and end of day trading strategies to determine if arbitrage opportunities exist. Creation/Redemption trading strategies seek to take advantage of any difference between the price of 50,000 DIAMONDs and that of the NAV of a Creation Unit of the Trust caused by the forces of supply and demand. The following illustrations outline the Creation and Redemption strategies:



On May 19, 2004, we collected stock data from Bloomberg in five second intervals and plugged this information into our trading model for four hours (between 11:00AM to 3:00PM, CST). The profitability data from our trading model was captured every five seconds for three hours for both the creation and redemption strategy. Testing the model on actual data produced the results that one would expect. Most of the time, the difference between the value of 50,000 DIAMONDs and the value of a Creation Unit for both strategies was negative, representing transactions costs, which were approximately \$2,000. While there were fleeting instances of mispricing throughout the day, execution speed, changes in the bid-ask spread of the DOW components, changes in the bid and ask spread of DIAMONDs, and order fill were variables that could quickly eliminate any arbitrage opportunities. The limited real time data that we collected demonstrated that a creation/redemption arbitrage would exist if the difference between the DOW basket plus cash component and a Creation Unit of DIAMONDS exceeded our trading costs of approximately \$2,000. The flat \$1,000 creation/redemption fee per day could be minimized if several creation/redemption trades were made in one day, but this is conditional on those trades materializing and being successfully captured.

## **IV. THEORY OF MARKET EFFICIENCY**

According to <u>Principles of Corporate Finance</u> by Brealey and Myers, there are three levels of market efficiency, which are distinguished by the degree of information reflected in security prices<sup>22</sup>:

- The weak form of market efficiency states that prices reflect the information contained in the record of past prices. Therefore, it is impossible to make consistently superior profits by studying past returns.
- The semi-strong form of market efficiency states that prices reflect not just past prices but all other public information. If markets are efficient in the semi-strong sense, prices adjust immediately to public information, such as earnings releases, merger announcements, dividend cuts, etc.
- The strong form of efficiency states that prices reflect all the information that can be acquired by analysis of the company and the economy. In such a market, there would be no superior investment managers who can consistently beat the market.

One purpose of this analysis and development of a trading strategy is to test the efficiency of the market for DIAMONDs and estimate which form of the efficient market hypothesis exists. Although our intra-day study of DIAMOND prices was limited to one day, our analysis suggested that at the very least the semi-strong form of efficiency holds in the DIAMONDs market, but to thoroughly examine efficiency, we performed more comprehensive statistical research.

<sup>&</sup>lt;sup>22</sup> Richard A. Brealey and Stewart C. Myers, "Corporate Financing and the Six Lessons of Market Efficiency", <u>Principles of Corporate Finance</u>, Seventh Edition, McGraw-Hill Irwin, p. 351.

## V. DATA SET

## **Data Selection**

Various studies, such as that by Hill and Mueller, suggest arbitrage opportunities in the ETF market to liquidity in the offsetting futures and options markets.<sup>23</sup> To explore the validity of this hypothesis (Hypothesis I), we decided to analyze the relationship between DOW Jones DIAMONDs to DOW Jones futures, over a two-and-half year period.<sup>24</sup>

## **Initial Spread Analysis**

We extracted end-of-day DIAMONDs prices and the end-of-day DIAMOND Net Asset Value (NAV) from the American Stock Exchange.<sup>25</sup> Over 572 trading days, from January 2, 2002 through May 7, 2004, the average mispricing (as defined by the difference between the price of DIAMONDs and DIAMONDs' NAV) was \$0.0067.<sup>26</sup>



Figure 1: The end-of-day DIA - DIA.NAV spread, 1/2/2002 - 5/5/2004

<sup>&</sup>lt;sup>23</sup> Joanne M. Hill and Barbara Mueller, "The Appeal of ETFs," Goldman Sachs Research Report, Fall 2001.

 <sup>&</sup>lt;sup>24</sup> DJIA futures began trading on the AMEX in January of 2002.
 <sup>25</sup> www.amex.com

<sup>&</sup>lt;sup>26</sup> DIA – DIA.NAV

While the mean spread suggests that arbitrage opportunities are small, the daily standard deviation was \$0.1741, indicating otherwise. The distribution of daily spreads resembles the normal distribution and is shown below, and although the median of the distribution was close to mean at \$0.01, the most frequently occurring observation (the mode) was - \$0.03.



Figure 2: Probability distribution of the DIA – DIA.NAV end-of-day spreads (1/2/02 – 5/5/2004)

The tails of the distribution suggest that arbitrage opportunities do exist (using end-of-day prices), from time-to- time, in the DIAMOND market. Our next step was to investigate the data to see what factors, if any, were common to the arbitrage opportunities, which could lead to an actionable arbitrage strategy.

## **Selecting Potential Independent Variables**

We then selected liquidity data for the same time period from the American Stock Exchange for the various securities DIAMOND market makers would use to hedge their DIAMONDs exposure, which is in line with the hypothesis I, proposed by Hill and Mueller (Bloomberg data source). These variables included:

- DOW Jones Industrial Average (DJIA) futures volume (all series)
- Open Interest on DJIA futures (all series)
- End of Day DJIA levels
- DJIA futures Put volume (all series)
- DIA daily opening prices
- DIA closing prices (adjusted)
- DIA high prices (daily)
- DIA low prices (daily)
- DIA volume
- DJIA futures Call volume (all series)

On a cursory glance, it appeared that hypothesis I, that a deficiency in futures liquidity leads to ETF mispricing, would be borne out. As the DJIA futures volume increased throughout their inaugural year (2002), the DIA – DIA.NAV spreads closed, and the variation of the spreads declined (although the change in variation was moderate). The graph below represents the average quarterly spread and standard deviation over time.



Figure 3: Characteristics of the end-of-day DIA- DIA.NAV spread over time

## **VI.** Linear Regressions and Results

To truly test hypothesis I, it was necessary to statistically link futures volume and the spreads. However, to improve their use in a predictive regression-based model, some of the variables listed above were modified. Modifications included time lags (adding or subtracting a day to a variable), taking the maximum observation across a series (i.e. creating a variable of "the max put volume," which would be the largest volume for any strike price and expiration of DJIA futures puts), or simple addition of two like variables (e.g. "Put + Call Volume"). In total, we developed over 50 metrics for use as independent variables in regression analysis.

#### **First Series of Regressions**

Our goal in performing the regression was to develop an equation or formula that could provide insight about the size of the DIA – DIA.NAV spread (the dependent variable) as a function of the independent variables. Given our previous discussion about futures volume and puts and calls, we believed such an equation may be:

**DIA** - **DIA**.**NAV** =  $\alpha$  -  $\beta_{\text{futures volume}}$  -  $\beta_{\text{puts} + \text{calls volume}}$ 

The since liquidity was anticipated to drive spreads down the coefficients for futures volume and options volume were expected to be negative. However, after running regressions, using all plausible combinations of the variables (both original and modified), we were unable to develop a model that significantly predicted the size of the DIA – DIA.NAV spread. The most predictive model, (in terms of adjusted r-squared) was:

DIA - DIA.NAV = 0.0119497 + 0.0000026<sub>futures volume</sub> - 0.0000028<sub>next day futures volume</sub>

However, there were significant problems with this model. As mentioned earlier, the r-squared and adjusted r-squared figures were extremely low (1.12% and 0.73%, respectively), dismissing the model's ability to predict a significant portion of the dependent variable (the spread). The variable's p-values were also unusually high (31% and 34%), indicating that the variables do not add value to the model. Additionally, while it serves as a viable regression variable, next day futures volume (developed using the "lag" technique) is unknown to an arbitrageur seeking to predict the spread on a given day.

This research did yield some interesting data. A given day's spreads were slightly positively correlated with the spread of the previous day and the subsequent day (0.0244 and 0.0245, respectively). This implies very slight positive serial correlation, as the chart below indicates, and suggests that spreads may persist.



Regression Equation: y = 0.0245x + 0.0065

Figure 4: Serial correlation between the current and previous day's DIA – DIA.NAV spread

Additionally, although the spreads exhibited negative correlation with the volume of puts and calls, which supported the hypothesis, it had a slightly positive correlation with futures volume, which contradicts the thesis. In either case, the correlations were not significant, (absolute values less than 0.07).

#### **Qualitative Work**

The first series of regressions showed no evidence that the wider ends of the distribution (the largest arbitrage opportunities) could be predicted. However, over the course of 572 trading days, there were ample opportunities to engage in arbitrage. Although we could not find a statistical model that predicted when these opportunities would emerge, we considered the potential for the largest mispricings to exhibit common patterns. To investigate the potential causes of these mispricings, we analyzed those that were roughly outside two standard deviations above or below the mean, greater or less than \$0.35. This accounted for 19 observations, or 3.3% of the entire sample. Please See Appendix I for this analysis.

This research provided no tangible "rules" for large mispricing, but three of the observations occurred on days that the DOW moved significantly.<sup>27</sup> Other observations occurred on days in which one or more of the 30 DOW components experienced a significant event. For example, on July 18, 2002, Philip Morris reported increased profits, but unexpected pessimism about the rest of the year and Microsoft reported a

<sup>&</sup>lt;sup>27</sup>+447 points (5.4%) July 29, 2002; +346 points (4.6%) October 1, 2002; -189 points (2.45%) October 4, 2002

profit of \$0.28 per share -- that includes a  $15\phi$  a-share deduction the company charged to its profits column, which corresponded with a DIA – DIA.NAV mispricing of -\$0.47.

## Second Round of Regressions

The investigation of the 19 largest mispricings led to another hypothesis (hypothesis II-A) that on days when the DOW index experiences substantial moves, the DIA -DIA.NAV is likely to be wide. In order to test this hypothesis, we developed dummy variables that would account for "large" changes in the DOW and "large arbitrage opportunities," based on pre-determined "break points," which could easily be adjusted. In addition to the dummy variables, we added a "modified spread" variable that only showed "large" spread observations (as determined by the aforementioned break point), and returned zero for all other observations. The modified spread would serve as the new dependent variable, and still enabled the degree of the spread to be considered, given it met the threshold to be considered large. We also introduced the signed volume variable, which took the sign (+ or -) from the change in the daily price of the DOW and applied it toward the DJIA futures volume figure, to make the futures volume a better predictive variable. Despite improvements to the input variables, the regression results were still uninformative in terms of predicting spreads, even if we changed the break points to include more or less of the total observations. Please see the summary of two sample regressions below.<sup>28</sup>

 $<sup>^{28}</sup>$  We should also note that whether using the actual spread, the modified spread, or a 0,1 dummy for the spread as the dependent variable, no regression models had the ability to predict DIA – DIA.NAV spreads.

		Number	Fraction of
	Break	Observations	<b>Total Observations</b>
DIA-NAV spread	\$0.35	19	3.32%
% Daily Change In Dow	3.1%	19	3.32%
	r-squared	0.31%	
adju	sted r-squared	-0.04%	
		Number	Fraction of
	Break	Observations	Total Observations
DIA-NAV spread	\$0.17	141	24.65%
% Daily Change In Dow	1.32%	141	24.65%
	r-squared	0.14%	
adju	sted r-squared	-0.21%	

We performed a similar analysis, to test hypothesis II-B, that changes in the DOW 30 components lead to large spreads. The methodology was extremely similar to that described above. First, daily returns for all 32+ DOW stocks were taken from Yahoo! Finance for January 1, 2002 to May 5, 2004 time period.<sup>29</sup> Then, a dummy variable was established that returned a 1 if there was a "large change" in any of the DOW stocks, otherwise a zero. Similar to the previous analysis, "large changes" were determined by a pre-determined break point. Again, we determined that a large change in any of the DOW 30 stocks had little predictive power over whether or not there would be a large spread, as the results below indicate.

<sup>&</sup>lt;sup>29</sup> American International Group Incorporated, Pfizer Incorporated and Verizon Communications Incorporated replaced AT&T Corporation, Eastman Kodak Company and International Paper Company on April 8, 2004.

		Number	Fraction of
	Break	Observations	<b>Total Observations</b>
DIA-NAV spread	\$0.35	19	3.32%
% Daily Chg In Any Dow Name	12.1%	19	3.32%
	r-squared	0.06%	
adju	usted r-squared	-0.12%	
		Number	Fraction of
	Break	Observations	Total Observations
DIA-NAV spread	\$0.17	141	24.65%
% Daily Chg In Any Dow Name	6.10%	140	24.48%
	r-squared	0.31%	
odiu			

#### **Time Analysis of Largest Spreads**

At this point, our analysis indicated that there was no statistical link between liquidity of offsetting DJIA futures and options and the spread between DIAMONDs and their NAV (rejection of hypothesis I). Similarly, after looking at the largest 19 observations, we developed hypotheses II-A and II-B, which large movements in the DOW or in any of its components may lead to arbitrage opportunities via large spreads between DIAMONDs and their NAV. However, regression analysis also led us to reject these hypotheses.

Finally, we decided to re-visit the idea of serial correlation that we discovered in our first series of regressions. The rejection of our first two hypotheses favored market efficiency. That is, they determined there was no way to predict large DIA – DIA.NAV spreads based on liquidity or large movements in the DOW. However, positive serial correlation suggests that spreads persist over time. In order to fully understand the persistence of spreads and the relationship between spreads from one day to the next, we used our 19 "large spread" observations. We looked at each observation and graphed the DIA –

DIA.NAV spread over 11 days: the five days before the large spread day, the day itself, and five days after the large spread day. To add more descriptive data to the process, we tracked the normalized signed DIAMONDs volume, based on a rolling 10 days, to see how much DIAMOND trading activity happened on these days. Interestingly, the spreads did not tend to persist in size. Regardless of whether a spread was positive (i.e. that the DIAMOND price exceeded the NAV) or negative (the DIAMOND price was less than the NAV), the large spread typically converged to zero (or crossed the axis) the very next day.

Additionally, in analyzing each of the eleven day periods, we found that the large mispricing days also tended to have the most extreme normalized signed volume. The graphs in Appendix II show the aggregated results of each of the four types of observations: those with a positive spread and positive signed volume on the large mispricing day (4 observations), those with a positive spread but negative signed volume (4 observations), those with a negative spread and positive signed volume (2 observations), and those with a negative spread and negative signed volume (9 observations).

## **VII.** Non-Linear Analysis and Results

The exhaustive linear regression showed that the various plausible independent variables like DJIA futures volume do not exhibit a linear relationship with the arbitrage opportunities. To develop a forecasting system, this study evaluated using technical indicators to identify trends in the market, and building a non-linear model to reconcile unclear trends and contradictory data.

## **Moving Averages**

Given that the first two rounds of regression provided little predictive power, we considered looking at moving averages to identify trends among the variables. Moving averages are one of the most popular and easy to use tools available to the technical analyst. They smooth out a data series and make it easier to spot trends, something that is helpful in volatile markets. They also form the building blocks for many other technical indicators and overlays. We used moving averages (low-pass filters<sup>30</sup>) in technical analysis to remove the random noise from a time series. This allowed us to discern the underlying trend or to determine prices at which we will take action. According to Tim Tillson, a perfect moving average<sup>31</sup>:

1. Would be smooth, not sensitive to random noise in the underlying time series. That is, its derivative would not spuriously alternate between positive and negative values.

<sup>&</sup>lt;sup>30</sup> Julius Bendat and Allan Piersol, *Engineering Applications of Correlations and Spectral Analysis*, John Wiley & Sons, Inc., 1993.

<sup>&</sup>lt;sup>31</sup> Tim Tillson, "Smoothing Techniques For More Accurate Signals," *Technical Analysis of Stocks and Commodities*, January 1998.

 Would not lag behind the time series from which it is computed. Lag, of course, produces late buy or sell signals that kill profits.

The only way a perfect moving average could be computed is to have knowledge of the future. There are several algorithms available to compute moving averages, but all of them lag or lead the time series to some extent.

## Simple Moving Average (SMA)

A Simple moving average (SMA) is formed by computing the average (mean) price of a security over a specified number of periods. The SMA is a lagging indicator and will always be "behind" the price. If the price of a security is trending down, the SMA will remain above the price. If the price were rising, the SMA would be below.

### Exponential moving Average (EMA)

In order to reduce the lag in simple moving averages, market technicians often use Exponential moving averages (also called exponentially-weighted moving averages). EMAs reduce the lag by applying more weight to recent prices relative to older prices. The weighting applied to the most recent price depends on the specified period of the moving average. The shorter the EMA's period, the more weight that will be applied to the most recent price. For example, a 10-period exponential moving average weighs the most recent price 18.18%, while a 20-period EMA weighs the most recent price 9.52%. The formula for a period-based EMA is:

EMA(current) = [(Price(current) - EMA(previous)] x Multiplier) + EMA(previous),

30

where the "Multiplier" is equal to 2/(1 + N) where N is the specified number of periods. The simple moving average has a lag, but the exponential moving average is prone to quicker breaks. Some traders prefer to use EMAs for shorter time periods to capture changes faster, and SMAs over long time periods to identify long-term trend changes.

#### Double Exponential moving Average (DEMA)

The Double Exponential Moving Average (DEMA) is a combination of a single exponential moving average and a double exponential moving average. Its advantage is that it gives a reduced amount of lag time than either of the two separate moving averages alone. The DEMA can be applied in the same manner as the Simple Moving Average or Exponential Moving Average. The DEMA is calculated as:

$$(2 * n-day EMA) - (n-day EMA of EMA),$$

where EMA = exponential moving average

DEMA<sup>32</sup> can track trending signals with zero lag, but it is noisier than other filtering techniques<sup>33</sup>.

#### *Tillson's Moving Average (T3)*

To address the smoothing, phase lag and overshoot problems with various moving averages, Tim Tillson proposed the T3 moving average<sup>34</sup>. Tillson's average is essentially a low-pass filter that exhibits a steeper roll-off, resulting in better filtering of high-

<sup>&</sup>lt;sup>32</sup> Mulloy, Technical Analysis of Stocks and Commodities, Feb. 1994

<sup>&</sup>lt;sup>33</sup> Julius Bendat and Allan Piersol, *Engineering Applications of Correlations and Spectral Analysis*, John Wiley & Sons, Inc., 1993.

<sup>&</sup>lt;sup>34</sup> Tim Tillson, "Smoothing Techniques For More Accurate Signals," *Technical Analysis of Stocks and Commodities*, January 1998.

frequency noise while still preserving the low-frequency components of a time series. The Tillson algorithm used for this study computes EMA, DEMA, and than computes a weighted moving average using volume factor, and number of sweeps.

#### Peak to Average Ratio (PAR)

The PAR is a ratio of the instantaneous value of a time-series to its time-averaged value. PAR is a measure of relative distance from a peak to floor of a data. PAR for this study, was defined as:

$$PAR = \frac{Spread(t)}{Floor},$$

where floor is threshold above which arbitrage can occur, i.e. \$0.35. PAR allows to convert a time-series from absolute to relative terms.

#### Artificial Neural Networks (ANN)

Application of artificial neural networks in financial markets is growing fast<sup>35,36,37,38</sup>. An artificial neural network is a model inspired by the structure of the brain that is well-suited for complicated tasks such as pattern recognition, data compression and optimization for which simple linear analysis is insufficient. A neural network approach gathers the numerical knowledge base in the form of weightings between the input, output and hidden layers and enables a multi-dimensional view of a problem.

<sup>&</sup>lt;sup>35</sup> Jason Kutsurelis, *Forecasting Financial Markets Using Neural Network: An Analysis of Methods and Accuracy*, M.S. Thesis, Naval Postgraduate School, California, 1998.

<sup>&</sup>lt;sup>36</sup> David Kil and Frances Shin, Pattern Recognition and Prediction with Applications to Signal Characterization, American Institute of Physics, New York, 1996.

<sup>&</sup>lt;sup>37</sup> Jacek M. Zurada, *Introduction to Artificial Neural Systems*, West Publishing House, Minnesota, 1992.

<sup>&</sup>lt;sup>38</sup> R.B. Caldwell, "Design of Neural Network-based Financial Forecasting Systems: Data Selection and Data Processing," NEUROVE\$T JOURNAL, Vol.2, No.5, pp. 12-20. 1994.

McCulloch and Pitts<sup>39</sup> outlined the first formal modal of an elementary computing neuron. A neural network is made up of a number of computational elements represented by circles in Figure 5:



Figure 5: A four-layer Artificial Neural Network

These elements are usually known as neurons, each of which is connected to other neurons. Each neuron can receive an array of inputs and produces a single output. The output of a neuron can either be a final network output or otherwise be transmitted through the neuron output connection paths to contribute to the input array of other neurons.

The transformation of the inputs to output, in the case of each neuron, is defined by a

<sup>&</sup>lt;sup>39</sup> Warren McCulloch and Walter Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity", *Bulletin of Mathematical Biophysics*, Pg. 5:115-133, 1943.

mathematical function known as the neuron transfer function. The transformation within a single neuron is relatively simple. The complexity of the neural network system is generally achieved by the interaction of several neurons. A Neural Network uses a network of nodes and connecting weights to represent the interaction between input and output parameters in a prediction model. The neural network model during training assigns appropriate weights to the input nodes of a network so that a weighted function of the input nodes predicts the outputs. Several algorithms can be used to develop these weights. For this study the Levenberg-Marquardt back propagation algorithm<sup>40</sup> was used. The back propagation algorithm calculates the error at the output nodes and passes it back through the hidden nodes to the input nodes adjusting the weights as the algorithm passes the error back to the input nodes. In the study we initially used a three-layer, fully connected network. In this type of network the first layer is composed of the input variables, the second layer is composed of hidden nodes and the last layer is composed of the output nodes. Later, a four-layer network with fully connected networks was tested and found to be more robust. The total input for any node *j* in the hidden or output layer is given by:

$$Y_j = \sum_{i=1}^l W_{ij} X_i$$

where i = 1, ..., l are all of the nodes in the previous layer and W<sub>ij</sub> is the connection weight.

The input  $X_j$  is transformed using a nonlinear activation function to a standardized  $Y_j$  for node *j*. The tangential-sigmoid and pure linear functions were used in this study. The neural network

<sup>&</sup>lt;sup>40</sup> Howard Demuth and Mark Beale, *Neural Network Toolbox for MATLAB*, The Mathworks, Inc., 1994.

additional layer of hidden nodes allows it to generate complex nonlinear mappings that may be useful in predicting chaotic phenomena such as DIA – DIA.NAV. A predetermined functional form that fits the data to the model constrains linear regression, while no predetermined functional forms constrain the neural network. A neural network can produce any non-linear functional form necessary to map a complex phenomena.

### Artificial Neural Network (ANN)

A hybrid approach<sup>41</sup> to ANN was chosen for the study. The reason for the hybrid approach is that it is important to optimize choice and number of inputs for the ANN. If a large number of arbitrary inputs are chosen than the model may never converge to a solution, or will become computationally prohibitive. The Hybrid ANN model was written in MATLB<sup>42</sup> language.

The following steps were undertaken to construct the ANN model:

- Pre-Processing: The initial data set has 592 data points (January 2<sup>nd</sup>, 2002 to May 6<sup>th</sup>, 2004). For the purpose of this study we picked \$0.35 as the spread above which a trader can profitably make an arbitrage trade. The pre-processing module of the model identified 19 arbitrage opportunities.
- 2) *Feature Extraction*: From the linear regression study we identified DIA Spread and DOW Futures Volumes as parameters that we want to consider for the ANN model.

<sup>&</sup>lt;sup>41</sup> David Kil and Frances Shin, *Pattern Recognition and Prediction with Applications to Signal Characterization*, American Institute of Physics, New York, 1996.

<sup>&</sup>lt;sup>42</sup> Howard Demuth and Mark Beale, *Neural Network Toolbox for MATLAB*, The Mathworks, Inc., 1994.

- 3) Feature/Target Optimization: After several iterations of feature and target selection, we identified Tillson Moving average as a feature that could be used to estimate trends in the spread. A 20-day Tillson moving average was computed with a 70% volume factor and 3 sweeps. This brought the number of dataset points down to 472 days (June 25<sup>th</sup>, 2002 to May 6<sup>th</sup>, 2004), which only includes 16 of our 19 "large spread" observations. The ANN model gives better results on relative rather than absolute basis. PAR was computed to calculate relative movements in spreads when compared to the arbitrage plane.
- 4) ANN Model: The data used to train and test the ANN model assumes that the dataset is complete and continuous, i.e. trading only takes place at the end-of-day prices. The time-series was divided into two sets. The 1<sup>st</sup> half (January 25<sup>th</sup>, 2002 to May 30<sup>th</sup>, 2003) of the dataset was used for training the model. The 2<sup>nd</sup> half (May 30<sup>th</sup>, 2003 to May 6<sup>th</sup>, 2004) of the dataset was used to test the predictability of the model. The model is first trained using the training dataset. The training of the model determined the various weightings for the neurons. Once the model is trained with a small network error, the model is ready to be validated using the test dataset. Below is description of the input and output layers of the Hybrid ANN model:

*INPUT*: The ANN model has three inputs:

- 1) Historic Peak-to-Average Ratio: PAR(t-5)
- 2) Historic Tillson 20-day Moving Average for DIAMOND Spread: T3(t-5),
- 3) Historic DOW Futures Volumes: DOW Volume(t-5)

*OUTPUT*: Current Spread (t), where t=current data.

Several neural network architectures were considered for the analysis (see Table 1).

	Sum Squared		Training Dataset		Fest Dataset	Neural Network
Case	ANN	Spread	Predicted Arbitrage	Spread	Predicted Arbitrage	Architecture -
Case	Convergence	RMS	(Actual Arbitrage = 11)		(Actual Arbitrage = 5)	Neurons
	Error	Error	(Actual Arbitrage – TT)	RIVIS EIIUI	(Actual Albitrage – 5)	(Layer 2, Layer 3)
1.	1.7868	0.0870	4	0.0526	1	18, 1
2.	6.1409	0.1610	0	0.1240	0	36, 2
3.	6.2000	0.1620	0	0.1350	0	36, 2
4.	0.0551	0.0153	8	0.0201	5	36, 2
5.	0.0894	0.0195	10	0.0212	5	36, 2
6.	0.0540	0.0151	8	0.1020	19	36, 2
7.	0.0383	0.0127	10	0.0242	5	36, 2
8.	8.4709	0.1890	1	0.1880	9	36, 2
9.	0.0983	0.0204	12	0.0287	5	36, 2
10.	0.0426	0.0134	11	0.0157	5	36, 2
11.	0.0649	0.0166	12	0.0113	6	36, 2
12.	0.0995	0.0205	11	0.0169	5	54,3
13.	9.1561	0.1970	0	0.1740	0	54,3
14.	0.0896	0.0195	9	0.0536	8	72,3
15.	0.00845	0.0060	11	0.0093	5	90,5

Table 1: Summary of results from selected runs of the Hybrid ANN

Table 1 shows results from multiple runs of the Hybrid ANN. The  $1^{st}$  column lists the run number. The  $2^{nd}$  column shows the overall sum squared error (SSE) of the model for the training dataset. The lower the network error, the better is the model's predictive power. The training error is shown in column 3. It is computed by calculating root-mean-square of the difference between the actual and computed spreads in the training dataset. A lower number signifies good training of the model. The  $4^{th}$  column shows the number of arbitrage opportunities predicted by the model using the training dataset. The training dataset has 11 points of arbitrage. The higher the network and RMS errors, the lower is the model's accuracy in predicting arbitrage opportunities. After the model was trained, it was tested using the test dataset. The  $5^{th}$  column shows the RMS error between

the actual and estimated spreads. A lower error means a superior accuracy in estimating spreads and predicting arbitrage. The  $6^{th}$  column shows the arbitrage opportunities predicted by the model using the test dataset. The dataset had a total of 5 arbitrage opportunities. The last column shows the number of neurons in the  $2^{nd}$  and  $3^{rd}$  layer of the neural network. The greater the number of neurons, the more complex is the network, resulting in an increase of computation time for running the model.

Based on the analysis above an adaptive four layered neural network was found best for the ETF arbitrage analysis. The 1<sup>st</sup> layer has three input neurons. The 2<sup>nd</sup> layer has ninety tangential sigmoid neurons. The 3<sup>rd</sup> layer has five linear neurons. And the 4<sup>th</sup> or outer layer has one output neuron. The model was trained using the training dataset (2/2002 to 4/2003), and validated using the test dataset (5/2003 to 5/2004). The results from the case 15 are shown in Figure 6 to Figure 10. The results from other selected runs are shown in Appendix III. Figure 6 shows the number of epochs needed to converge to the final SSE for the network. Each epoch for the model was 100 to 200 iterations of running the neural network training algorithm. Figure 7 shows the actual and predicted spreads for the training dataset. Errors tended to increase if the volatility of the spread is high. The

Figure 8 shows the arbitrage opportunities in the training and predicted dataset. The arbitrage points are accurately predicted when the spread is high. If the spread is close to the \$0.35 threshold, an arbitrage opportunity may not be predicted by the model due to network error as shown in Table 1. It is recommended that instead of using a cut-off point, an error band should be used to compensate for the error in the ANN prediction.

The Figure 9 shows the actual and predicted spread in the test dataset. The validation step is essential in determining the robustness of the ANN approach. The results show that around September 8<sup>th</sup>, 2003 when volatility in spreads were high the errors increased. The input to the ANN model has a 20-day moving average. Adding a 5-day lag moving average may help in reducing the error during extreme swings in the market. Even though the predicted spreads were not complete accurate, the model predicted all the arbitrage cases in the test dataset, as shown in Figure 10.



Figure 6: Sum Squared Error for Network Training = 0.00845 (Case 15)



Figure 7: Results from training ANN - Spread (Case 15)



Figure 8: Results from training ANN - Arbitrage (Case 15)



Figure 9: Validating ANN – Spread (Case 15)



Figure 10: Validating ANN – Arbitrage (Case 15)

#### Training Data Regression (Case 15)



Figure 11: Regression results from actual and ANN spread for training data (Case 15)



Figure 12: Regression results from actual and ANN spread for test dataset (Case 15)

The Figure 11 shows the regression between the actual and predicted spreads for the training dataset. The Figure 12 shows the same regression for the test dataset. Both the training and validation phases showed high  $R^2$  values. The Hybrid ANN model with the case 15 configuration is able to predict all opportunities of arbitrage with good accuracy.

## VIII. APPLICATION OF ANN TO TRADING STRATEGY

### **Quantifying Transaction Expenses**

In order to develop a hurdle rate to determine arbitrage opportunities, it is valuable to consider the per DIAMOND transaction expenses associated with a creation/redemption strategy. The following table summarizes the transaction costs that would be incurred if a trader entered into a creation/redemption strategy.

	Creation Unit	Per Diamond
Transaction costs		
Creation fee	-1000	-0.0200
Commission on Dow		
components	-532.95	-0.0107
Commission on 50,000 DIA	-250	-0.0050
Participating Party	-150	-0.0030
	-1932.95	-0.038659
1/2 Bid / Ask Diamond		-0.02
<sup>1</sup> / <sub>2</sub> Bid / Ask Dow (average stock)		-0.032025
Total transaction costs		-0.090684

The creation fee is the same as discussed in the Overview of ETFs (Section II). The commission on DOW components and 50,000 DIAMONDs are simply the agency commissioned paid to brokers for making trades. The Participating Party Fee is a handling fee paid to a group that is a certified broker/dealer in the DIAMONDs clearing process.

Traders also need to consider bid-ask spreads of both DIAMONDs and the DOW components. Market data collected on May 5, 2004 indicated that the average bid-ask spread for DIAMONDs was \$0.04 at any given time. Similarly, the average bid-ask

spread across all DOW 30 stocks was \$0.03.<sup>43</sup> However, when a trader engages in a creation/redemption strategy he/she is only engaging in one-half of a round trip bid-ask spread (either buying or selling, not both). The other half of the spread is covered when DIAMONDs (from the trustee) are applied to the open DIAMONDs position (whether it be short or long), as described in the .

We should note that this \$0.09/DIAMOND account for transaction expenses *does not include the price impact of trading entire creation units of DIAMONDs*. An order to buy or sell 50,000 DIAMONDs could substantially impact the opportunity for arbitrage and could impose a more serious hurdle than the \$0.09 of transaction expenses. Therefore, it is likely that the arbitrage hurdle is closer to \$0.20 (or even \$0.30) than to the \$0.09 we were able to detail above.

#### **Arbitrage Methodology**

This initial predictive success of the ANN-based model, suggests that traders may benefit from using such a model. Application would involve the following steps:

At the end of a trading day, input the end-of-day variables (PAR [5 day lag], 20 day Tillson's Moving Average of the DIA-DIA.NAV spread [5 day lag], DJIA futures volume [5 day lag]) into the model and predict the DIA-DIA.NAV spread for the following day.

<sup>&</sup>lt;sup>43</sup>This figure is not actually shown in raw form in the table. First, it is halved to reflect that only half of the round trip is incurred. Then it is increased by a multiplier of 2.13, which was determined by dividing the end-of-day price of DIAMONDs on May 5, 2004 to the end-of-day price of an "average" DOW component on May 5, 2004. This multiplier takes into account the fact that a trader would have to trade approximately twice as many shares of stock (~100,000) of the 30 components to achieve the same notional amount as one 50,000 DIAMOND creation unit. The end product is .03/2 \* 2.13 or ~ .03.

- Assess whether the predicted end-of-day DIA-DIA.NAV spread constitutes an "arbitrage opportunity," as defined by the trader.
- 3. If the predicted spread is sufficiently positive, suggesting that DIAMONDs exceed their fair value by an amount large enough to earn an arbitrage profit, a trader would then submit trading instructions the next day to sell DIAMONDs on close and buy the basket of stocks (and requisite cash payments associated with creation/redemption) on close.
- 4. If the predicted spread is sufficiently negative, suggesting that DIAMONDs NAV is greater than the price of DIAMONDs, traders would submit buy on close orders (the next day) for DIAMONDs and sell on close orders for the underlying basket of stocks (and requisite cash payments associated with creation/redemption).
- 5. At this point, depending on whether the trader bought or sold DIAMONDs he/she will engage in the appropriate creation/redemption strategy that will unwind the long or short position by depositing or withdrawing the diamonds into their trading account.

## **IX. CONCLUSION**

The results from testing hypotheses I, II-A, and II-B indicated that traditional statistical models based on linear regression are not robust tools for predicting mispricings in the market for DIAMONDs. Furthermore, these results suggested that the DIAMONDs market is considerably efficient.

However, our model based on Artificial Neural Networks (ANN) showed great promise, predicting sixteen out of sixteen "arbitrage opportunities." Prior to engaging in arbitrage based on ANN, traders should train and test models using a dataset from a time horizon longer than two years, consider more independent variables, and incorporate intra-day prices and spreads into training data. The Hybrid ANN model can be improved by using technical indicators like Relative Strength Index, Money Floor Index, Stochastic Oscillator, Moving Average Convergence Divergence.

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## **XI. APPENDICES**

## Appendix I

Date         The Week         Spread         Previous Day         In Dow (Price)         In Dow (Price)         Activity         Open interest         Youne         Component News         Chainman of the Secrities and Exponsed a trughter governing body for accuraters to prevent future Erin Bie debades           1         1/17/2002         Thursday         -0.44         (0.13)         146         1.4%         None         717         87         HP being sued over impropriets in the shareholder vole on the HP- Company merger. Among the accusations, that HP wrongly enticed a major shareholder vole on the HP- Company merger. Among the accusations, that HP wrongly enticed a major shareholder vole on the HP- Company merger.           2         328/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27,021         11.541         of the merger.         Houng static role 116 percentin major shareholder vole on shareholder vole on shareholder vole on shareholder to way the biggers imprin 7 years. All this, with no inflation. The CPI May was flat           3         6/19/2002         Tuesday         0.59         (0.05)         (117)         1.3%         None         31,885         32,204         Philip Morris reported increased profits. Not unexpected pessimism abuit the schedelscholden the company charged to its portis to costing bit. Microsoft reported a costing bit. Microsoft reported a mal weepceted do for merger.           5         7/19/2002         Thursday			Day of	DIA-DIA.NAV	DIA-DIA.NAV	Daily Chg	Daily Chg	Add/Delete	Dow Futures	Dow Futures	Dow	Other/Macro	
Image: Provide Contraction         Contrac		Date	the Week	Spread	Previous Day	in Dow (Price)	in Dow (%)	Activity	Open Interest	Volume	Component News	News	
1         1/17/2002         Thursday         -0.44         (0.13)         146         1.4%         None         717         87         Bit of accumation to prevent future Eron like detacles           2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27.021         11,641         of the merger. mager Among the accusations, that HP wongly enticed a major shareholder to solve thin favor           2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27.021         11,641         of the merger.           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39,494         28.688         unwastation         The CPI May was flat           4         7/12/2002         Filday         -0.37         (0.05)         (117)         1.3%         None         31,895         33.204         contidence in July           4         7/12/2002         Filday         -0.37         (0.05)         (117)         1.3%         None         31,895         29.666         column           5         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None												Exchange Commission Harvey Pitt	
Image: 1         1/17/2002         Thursday         0.44         (0.13)         146         1.4%         None         717         87         HP being sued over improprieties in like debades           1         1/17/2002         Thursday         0.40         (0.05)         (22)         -0.2%         None         27.021         11.541         HP being sued over improprieties in like debades           2         3/28/2002         Thursday         0.40         (0.05)         (22)         -0.2%         None         27.021         11.541         Housing starts rose 11.6 percent in May, the biggest jump in 7 years. All this, with ne west fail           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39.494         28.688         University of Mering negot showed an unexpected drop in consume onfidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         University of Mering negot showed an unexpected drop in consume onfidence in July           5         7/18/2002         Thursday         -0.47         (0.17)         1.32         None         31.395         20.686         courn           5         7/18/2002         Thursday												proposed a tougher governing body	
1         1/17/2002         Thursday         -0.44         (0.13)         146         1.4%         None         717         67         Ille debades           HP being sued over imporpieties in the shareholder volte on the HP. Compaging merger. Among the accusations, that HP wrongly enticed a major shareholder to switch in favor         1.6 <td></td> <td>for accountants to prevent future Eron-</td>												for accountants to prevent future Eron-	
2         20000         100         100         100         100         100         100         100         100         100         100         110 <td>1</td> <td>1/17/2002</td> <td>Thursday</td> <td>-0.44</td> <td>(0.13)</td> <td>146</td> <td>1.4%</td> <td>None</td> <td>717</td> <td>87</td> <td></td> <td>like debacles</td>	1	1/17/2002	Thursday	-0.44	(0.13)	146	1.4%	None	717	87		like debacles	
2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27,021         11,541         of the merger.           2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27,021         11,541         of the merger.         Housing starts rose 11.6 percent in May, the biggest jump in 7 years. All this, with no inflation. The CPI May, the biggest jump in 7 years. All this, with no inflation robe of thom prior is reported increased university of Michigan report showing neops thoward an unexpected drop in consumer confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         University of Michigan report showard an unexpected drop in consumer confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         Confidence in July           6         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column         Includes a Jicent a-share deduction the company hard in Molay shares fiel 62 percent aneed dot is quarterly shares fiel 62 percent aneed dot is quarterly shares fiel 62 percent aneed dot is quarterly shares fiel 62 percent						-					HP being sued over improprieties in		
2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27.021         11,541         Compage merger. Among the accistions, that HP wongly enticed a major shareholder to switch in favor of the merger.           3         6/18/2002         Tuesday         -0.40         (0.05)         18         0.2%         None         39.494         28.688         Housing starts rose 11.6 percent in the QPI May the biggest jump in 7 years. All this, with no inflation. The QPI May was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         University of Michigan report showed an unexpected drop in consumption and unexpected profils. Dure showed there was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         Initiation flat in the part of the merger.           5         7/16/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31.395         29.666         column         Third biggest point gain in DJIA hostory           5         7/16/2002         Thursday         -0.48         0.13         447         5.4%         None         33.128         33.											the shareholder vote on the HP-		
2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27.021         11.541         of the merger.           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39.494         28.688         Housing starts rose 11.6 percent in May, the biggest jump in 7 years. All           4         7/12/2002         Friday         -0.37         (0.05)         18         0.2%         None         31.895         33.204         University of Mathiano. The CPI May was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         University of Mathiano. The CPI May was flat           7         1.15%         None         31.895         33.204         Philip Morris reported increased particle increased profits. Jou mayepeted pessimism about the rest of the year. After the close of targing about the rest of the year. After the close of targing about the rest of the year. After the close of targing and the company worked to a mid year assessment from the company worked to a mid year assessment from the company worked to a mid year assessment from the company worked to a mid year assessment from the company worked to a mid year assessment from the company worked to a mid year assessment from the company worked to a mid year assessment from the company wore the service sector four year set of tading and the											Compag merger. Among the		
2         3/28/2002         Thursday         0.40         (0.05)         (22)         -0.2%         None         27,021         11,541         of the energer.         Housing stafs rose 11.6 percent in May, the biggest jupin 17 years. All this, with no inflaton. The CPI May           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39,494         28,688         University of Michigen report showed an unexpected rop in onsumer confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         Philip Morris reported increased profits, but unexpected passimism about the rest of the year. After the closing bell, Microsoft reported a profit of 28 cents per share - that includes a 1.5 cents - ashare deduction the company charged to its profits           5         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column         Third biggest point gain in DJIA           6         7/29/2002         Monday         -0.48         0.13         447         5.4%         None         33,128         33,244         Third biggest point gain in DJIA           7         9/5/2002         Thursday         0.36         (0.32)         141											accusations, that HP wrongly enticed		
2         3/28/2002         Thursday         -0.40         (0.05)         (22)         -0.2%         None         27.021         11.541         of the merger.           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39.494         28.688         Housing starts rose 11.6 percent in May, the biggest jump in 7 years. All this, with on flation. The CPI May was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         University of Michigan report showed an unexpected drop in consumer confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31.895         33.204         Confidence in July           4         7/12/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31.395         29.666         column           5         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31.395         29.666         column           6         7/29/2002         Monday         -0.48         0.13         447         5.4%         N											a major shareholder to switch in favor		
3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39,494         28,688         May, the biggest jump in 7 years. All this, with no inflation. The CPI May was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         Philip Morris reported increased profits, but unexpected for in consumer confidence in July           5         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column         Third biggest point gain in DJIA history           6         7/29/2002         Monday         -0.48         0.13         447         5.4%         None         33,128         33,244         Third biggest point gain in DJIA history           6         7/29/2002         Monday         -0.48         0.13         447         5.4%         None         33,128         33,244         Austral           7         9/5/2002         Thursday         0.36         (0.32)         141         1.7%         None         32,960         27,634         61 action a	2	3/28/2002	Thursday	-0.40	(0.05)	(22)	-0.2%	None	27,021	11,541	of the merger.		
Age, the biggest jump in 7 years. All           3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39,494         28,688         Was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         University of Michigan report showed an unexpected drop in consumer confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         Confidence in July           9         Philip Morris reported increased profits J28 cents persare - that includes a 15-centa-share deduction the corpany charged to its profits         Tursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column           6         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column           6         7/18/2002         Monday         -0.48         0.13         447         5.4%         None         33,128         33,224         Mait me ported slow sales. Intel shares fiell 6.2 percent hahead of a mid year assesment from the company that a company thar												Housing starts rose 11.6 percent in	
3         6/18/2002         Tuesday         0.59         (0.05)         18         0.2%         None         39,494         28,688         this, with no inflation. The CPI May was flat           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         University of Michigan report showed an unexpected drop in consume confidence in July           4         7/12/2002         Friday         -0.37         (0.05)         (117)         1.3%         None         31,895         33,204         Philip Morris reported increased profits, but unexpected pessimin about the rest of the year. After the closing bell. Microsoft reported a profit of 28 cents per share - that includes a 15-cent-a-share deduction the company charged to its profits           5         7/18/2002         Thursday         -0.47         (0.17)         (132)         1.5%         None         31,395         29,666         column           6         7/29/2002         Monday         -0.48         0.13         447         5.4%         None         33,128         33,244         Mistory           Value was a fiel           7         9/5/2002         Thursday         0.36         (0.32)         141         1.7%         None         32,280         27,634												May, the biggest jump in 7 years. All	
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4       7/12/2002       Friday       -0.37       (0.05)       (117)       1.3%       None       31,895       33,204       an unexpected drops and profits consumer confidence in July         4       7/12/2002       Friday       -0.37       (0.05)       (117)       1.3%       None       31,895       33,204       confidence in July         4       7/12/2002       Friday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       coloring bell, Microsoft reported a profit of 18 profits         5       7/18/2002       Monday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column       the company charget to its profits         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Maitory         Wal-Mart reported slow sales. Intel shares feli 6.2 percent ahead of a mid year assessment from the company moved its quarterly and the company and the company and the company and the core of trading and the company charact alabs.       A surv	3	6/18/2002	Tuesday	0.59	(0.05)	18	0.2%	None	39,494	28,688		was flat	
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4       7/12/2002       Finday       -0.37       (0.05)       (117)       1.3%       None       31,895       33,204       contidence in July         6       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         6       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Maint reported slow sales. Intell shares fell 6.2 percent ahead of a mid year assessment from the company moved its quarterly sales forecast toward the lower end and the company moved its quarterly sales forecast toward the lower end and the company moved its quarterly sales forecast toward the lower end and the contrans taits.       A survey of the service sector found more weakness than than expected         7       9/5/2002		7/10/0000			(0.05)	(4.4.7)	4.004					an unexpected drop in consumer	
<ul> <li>Fhilp Morris reported increased profits, but inexpected pessimism about the rest of the year. After the closing bell. Microsoft reported a profit of 28 cents per share that includes a 15-cent-a-share deduction the company charged to its profits</li> <li>Thursday -0.47 (0.17) (132) 1.5% None 31,395 29,666 column</li> <li>Third biggest point gain in DJIA</li> <li>7/29/2002 Monday -0.48 0.13 447 5.4% None 33,128 33,244</li> <li>Wal-Mart reported slow sales. Intel shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company index at the lower end A survey of the service sector found that came after the close of trading and the company invoked its quarterly sales forecast toward the lower end A survey of the service sector found Union workers at the Port of Los Angeles began a slowdow after 5</li> <li>9/18/2002 Wednesday -0.57 (0.18) (35) 0.4% None 47,775 45,548</li> <li>9/18/2002 Tuesday 0.52 (0.01) 346 4.60% None 29,561 35,178</li> <li>LA. Jury orders Philip Morris to Pay</li> </ul>	4	//12/2002	Friday	-0.37	(0.05)	(117)	1.3%	None	31,895	33,204		confidence in July	
7       9/5/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         5       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         5       7/18/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,224       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,224       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,224       Third biggest point gain in DJIA         None       33,128       33,224       Mainterported slow sales. Intel         shares fell 6.2 percent ahead of a mid         year assessment from the company worked its quarter A         year assessment from the company worked its quarter A         sales forecast toward the lower end         A survey of the service sector found         monto sales forecast toward the lower end       A survey of the serv											Philip Morris reported increased		
<b>5</b> 7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column       tis profits <b>5</b> 7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column       Third biggest point gain in DJIA <b>6</b> 7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA <b>6</b> 7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA <b>7</b> 9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range more weakness than than expected <b>7</b> 9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range more weakness than than expected         Union workers at the Poot of Los       Angeles began a slowdown of Los       Angeles began a slowdown of Los       Angeles began a slowdown of Los <b>8</b> 9/18/2002 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>profits, but unexpected pessimism</td><td></td></t<>											profits, but unexpected pessimism		
5       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column       the company charged to its profits         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       history              Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       history              Wal-Mart reported slow sales. Intel       shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company moved its quarterly sales forecast toward the lower end       A survey of the service sector found         7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found              A survey of the service sector found       Mone wakness than than expected <td colu<="" td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>about the rest of the year. After the</td><td></td></td>	<td></td> <td>about the rest of the year. After the</td> <td></td>											about the rest of the year. After the	
5       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       history         Wal-Mart reported slow sales. Intel shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company moved its quarterly sales forecast toward the lower end A survey of the service sector found         7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       more weakness than than expected         Union USE gains for a store of the off a mid year assessment from the company moved its quarterly sales forecast toward the lower end A survey of the service sector found         7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       more weakness than than expected         Union vorkers at the Port of Los Angeles began a slowdow											closing bell, Microsoft reported a		
5       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       history         Wal-Mart reported slow sales. Intel shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company moved its quarterly sales forecast toward the lower end Union workers at the Port of Los       A survey of the service sector found more weakness than than expected Union workers at the Port of Los         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       29,561       35,178       Months of contract talks.         Surge in Dow. Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.											profit of 26 certis per share that		
5       7/18/2002       Thursday       -0.47       (0.17)       (132)       1.5%       None       31,395       29,666       column         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA history         6       7/29/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Wal-Mart reported slow sales. Intel shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company moved its guarerly sales forecast toward the lower end A survey of the service sector found more weakness than than expected         7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       months of contract talks.         8       9/18/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       LA Jury orders Philip Morris to Pay <td></td> <td>the company charged to its profits</td> <td></td>											the company charged to its profits		
• 1/10/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA history         • 7       9/5/2002       Monday       -0.48       0.13       447       5.4%       None       33,128       33,244       Third biggest point gain in DJIA history         • 7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       Monthe expected         • 7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       Union workers at the Port of Los Angeles began a slowdown after 5         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       Surge in Dow. Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.	5	7/18/2002	Thursday	-0.47	(0.17)	(132)	1.5%	None	31 395	29 666	column		
67/29/2002Monday-0.480.134475.4%None33,12833,244HistoryWal-Mart reported slow sales. Intel shares fell 6.2 percent ahead of a mid year assessment from the company that came after the close of trading and the company moved its quarterly sales forecast toward the lower end and the company moved its quarterly sales forecast toward the lower end the lower end A survey of the service sector found more weakness than than expected Union workers at the Port of Los Angeles began a slowdown after 5 months of contract talks.79/18/2002Wednesday-0.57(0.18)(35)0.4%None47,77545,54845,548Surge in Dow. Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.910/1/2002Tuesday0.52(0.01)3464.60%None29,56135,178LA. Jury orders Philip Morris to Pay		1110/2002	marsaay	-0.+1	(0.17)	(102)	1.070	None	01,000	23,000	column	Third biggest point gain in D.IIA	
Wal-Mart reported slow sales. Intel         shares fell 6.2 percent ahead of a mid         year assessment from the company         that came after the close of trading         and the company moved its quarterly         sales forecast toward the lower end         A survey of the service sector found         more weakness than than expected         Union workers at the Port of Los         Angeles began a slowdown after 5         months of contract talks.         Surge in Dow. Explanations: the fresh start of a new financial quarter         and progress on U.N. weapons         inspections.         L.A. Jury orders Philip Morris to Pay	6	7/29/2002	Monday	-0.48	0.13	447	5.4%	None	33,128	33,244		history	
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       45,548       Union workers at the Port of Los Angeles began a slowdown after 5 months of contract talks.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       LA, Jury orders Philip Morris to Pay									,				
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       45,548       Surge in Dow. Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.											Wal-Mart reported slow sales. Intel		
year assessment from the company that came after the close of trading and the company moved is quarterly sales forecast toward the lower end of a previously announced range. 9 10/1/2002 Tuesday 0.52 (0.01) 346 4.60% None 29,561 35,178 L.A. Jury orders Philip Morris to Pay											shares fell 6.2 percent ahead of a mid-		
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       45,548       Union workers at the Port of Los Angeles began a slowdown after 5         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       L.A. Jury orders Philip Morris to Pay											year assessment from the company		
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       45,548       Union workers at the Port of Los Angeles began a slowdown after 5 months of contract talks.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.											that came after the close of trading		
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       A survey of the service sector found more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       Surge in Dow. Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       L.A. Jury orders Philip Morris to Pay											and the company moved its quarterly		
7       9/5/2002       Thursday       0.36       (0.32)       141       1.7%       None       32,960       27,634       of a previously announced range.       more weakness than than expected         8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       Angeles began a slowdown after 5 months of contract talks.         Surge in Dow.       Explanations: the fresh start of a new financial quarter and progress on U.N. weapons       Surges on U.N. weapons         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       L.A. Jury orders Philip Morris to Pay											sales forecast toward the lower end	A survey of the service sector found	
8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       Angeles began as lowdown after 5 months of contract talks.         Surge in Dow.       Surge in Dow.       Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.         9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.	7	9/5/2002	Thursday	0.36	(0.32)	141	1.7%	None	32,960	27,634	of a previously announced range.	more weakness than than expected	
8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       Angeles began a slowdown after 5 months of contract talks.         Surge in Dow.       Explanations: the fresh start of a new financial quarter and progress on U.N. weapons inspections.       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.												Union workers at the Port of Los	
8       9/18/2002       Wednesday       -0.57       (0.18)       (35)       0.4%       None       47,775       45,548       months of contract talks.         Surge in Dow.       Explanations: the fresh start of a new financial quarter and progress on U.N. weapons       9       10/1/2002       Tuesday       0.52       (0.01)       346       4.60%       None       29,561       35,178       inspections.		0.11.0.100.000			(0.40)	(0.5)	0.404					Angeles began a slowdown after 5	
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9 10/1/2002 Tuesday 0.52 (0.01) 346 4.60% None 29,561 35,178 inspections.												Surge in Dow. Explanations: the	
9 10/1/2002 Tuesday 0.52 (0.01) 346 4.60% None 29,561 35,178 inspections.												and progress on U.N. weepone	
L.A. Jury orders Philip Morris to Pav	٩	10/1/2002	Tuesday	0.52	(0.01)	346	4 60%	None	29 561	35 178		inspections	
		10/1/2002	lucoudy	0.02	(0.01)	070	7.0070	None	20,001	00,170	L.A. Jury orders Philip Morris to Pay		
10 10/4/2002 Friday 0.56 0.09 (189) -2.45% None 31,516 36,130 \$28 Billion	10	10/4/2002	Friday	0.56	0.09	(189)	-2.45%	None	31,516	36,130	\$28 Billion		
11         10/7/2002         Monday         0.39         0.56         (106)         -1.40%         None         31,772         30,066         President's speech on Iraq.	11	10/7/2002	Monday	0.39	0.56	(106)	-1.40%	None	31,772	30,066		President's speech on Iraq.	

## Appendix I (Continued)

Enron's former O Andrew Fastow, fraud, money la obstruction diversion of mil 12 10/31/2002 Thursday -0.37 (0.06) (30) -0.36% None 32,529 21,285 The housing October are do October are do	r/Macro ews
12         10/31/2002         Thursday         -0.37         (0.06)         (30)         -0.36%         None         32,529         21,285         Own e           The housing October are do	ief Financial Officer, ndicted on counts of ndering, conspiracy,
12         10/31/2002         Thursday         -0.37         (0.06)         (30)         -0.36%         None         32,529         21,285         Own e           October are do	justice, and the
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Orthore are do	tarts number for
	n 11.4 nercent the
<b>13</b> 11/20/2002 Wednesday 0.51 0.18 148 1.75% None 34.428 25.741 biggest biggest	p in 9 vears.
Iraqis celebrate	downtown Baghdad
amid U.S. N	litary presence.
Rumsfeld warns	ighting in Iraq is not
over and that	very difficult and
<b>14</b> 4/9/2003 Wednesday 1.46 0.05 (101) -1.22% None 29,854 24,336 dangerous	ays lay ahead."
Job cuts increas	TIMING: the Feds
<b>15</b> 8/5/2003 Tuesday -0.46 (0.05) (150) -1.63% None 41,776 19,041 bar MCI	t is Sprint next?
	reduced. Pace of
UAW negotia	ons picks up after
<b>_16</b> 9/5/2003 Friday -0.74 0.09 (85) -0.88% None 48,084 16,816 La	or Day.
Increased reg	atory interest has
some mutual	unds shifting into
damage contro	mode: promising to
reimburse the i	estors who trusted
17 9/8/2003 Monday 0.84 (0.74) 83 0.87% None 47,352 14,701	iem
A federal judge	es the go-ahead for
victums and r	atives of the 9/11
attacks to pursu	negligence lawsuits
against America	and United Airlines,
40 0/0/0002 Tuesday 0.00 0.04 (70) 0.020/ Name 47.040 40.007	
10         3/3/2003         Luesday         -0.00         0.84         (/9)         -0.83%         None         4/,640         12,06/         2000	
Senare rejects tr 19 9/10/2003 Wednesday -0.63 (0.66) (87) -0.91% None 50.566 31.716 chapters to fede	administration's













## Appendix III



Figure 1: Dataset used for ANN analysis has 16 arbitrage points (6/24/02 - 05/08/04)



Figure 2: PAR for dataset used for ANN analysis (6/24/02 - 05/08/04)



Figure 3: Sum Squared Error for Network Training = 0.0383 (Case 7)



Figure 4: Sum Squared Error for Network Training = 0.0995 (Case 12)



Figure5: Results from training ANN - Spread (Case 7)



Figure 6: Results from training ANN - Arbitrage (Case 7)



Figure 7: Validating ANN – Spread (Case 7)



Figure 8: Validating ANN – Arbitrage (Case 7)



Figure 9: Results from training ANN - Spread (Case 12)



Figure 10: Results from training ANN - Arbitrage (Case 12)



Figure 11: Validating ANN – Spread (Case 12)



Figure 12: Validating ANN – Arbitrage (Case 12)



Figure 13: Results from training ANN - Spread (Case 13)



Figure 14: Results from training ANN - Arbitrage (Case 13)



Figure 15: Validating ANN – Spread (Case 13)



Figure 16: Validating ANN – Arbitrage (Case 13)





Figure 22: Regression results from actual and ANN spread for training data (Case 1)



#### Test Data Regression (Case 1)

Figure 23: Regression results from actual and ANN spread for validation data (Case 1)