Intraday Index Volatility: Evidence From Currency Adjusted Stock Indices

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ABSTRACT

A recent research stream develops currency adjusted stock indices. The analysis in previous papers is limited to daily closing data. This paper extends the existing body of literature by examining tick data. We examine tick data from 2002 through 2013 for eight indices. In general, results show the Dollar Index adjusted indices display significantly lower variation than the unadjusted indices. Correlation between the Dollar Index and unadjusted stock indices is negative. Both raw and Dollar index adjusted indices display departures from intra-tick symmetry. The results also show that Dollar Index changes explain as much as fifteen percent of wealth changes.

Keywords: Stock Index; Dollar Index; Currency Value

INTRODUCTION

*S*tandard stock indices are based on the domestic currency. Fluctuation in the underlying currency value distorts purchasing power changes implied by index level changes. Currency adjusted indices capture wealth changes resulting from both stock value changes and currency value changes. As such, currency adjusted indices provide a better measure of wealth changes. A recent article by Jalbert (2012) develops the first known currency adjusted stock indices. He develops indices using U.S. stock indexes as adjusted using the Major and Broad currency value measures available from the U.S. Federal Reserve. He uses close of day index and currency data to develop his currency-adjusted indices. This approach suffers from several limitations as noted in Jalbert (2014). A critical limitation of these indices is that Major and Broad currency value data are only available for close of day values. The lack of intraday data limits the usefulness of these indices for individuals interested in more frequent index valuations.

In a later paper, Jalbert (2014) uses Dollar Index (DXY) data as an alternative to Major and Broad currency values. Dollar Index data has the advantage of intraday quotations, futures contract availability and is available in exchange traded and mutual funds. Moreover, the Dollar Index is widely reported in news outlets. The Dollar Index was initiated in 1973 with a value of 100. Higher index values indicate a stronger dollar value.

This paper extends the work of Jalbert (2012) and Jalbert (2014). Like Jalbert (2014), this paper uses the Dollar Index for computing currency adjusted indices. Jalbert (2014) limited his analysis to close of day index values. This paper extends the literature by examining intraday data. The remainder of the paper is organized as follows. The following two sections provide a review of the relevant literature and discussion of the data and methodology used in the paper. Next, the test results are presented. The paper closes with some concluding comments and suggestions for future research.

LITERATURE REVIEW

A large body of literature addresses stock indices. However, only two known papers examine currency value adjusted indices. Thus we relate this study to general literature on stock indices. We examine three lines of literature, the relationship between stock indices and stock index futures, stock index volatility, and stock price reactions to stock index component changes.

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One line of literature examines the extent to which cycles occur in stock index levels, returns and volatility. If predicable cycles exist, the market does not conform to weak form market efficiency. Alvarez-Ramirez and Rodriguez (2011) examine the Dow Jones Industrial Average (DJIA) for cyclical patterns. They find cycles appear with frequencies between 4.5 and 22 years. Wong, Lian and Cheong (2009) find the DJIA has volatility cycles with index changes following a Gaussian process. Opong, Mulholland, Fox and Farahmand (1999) find the London Financial Times Stock Exchange, All Share Index has cycles that occur more often than expected under a random series.

Lakonishok and Smidt (1998) examine DJIA seasonality patterns. Over a ninety-year period, they find persistent turn of the week, month, and year patterns along with holiday return anomalies. Donaldson and Kim (1993) find support and resistance levels around DJIA multiples of 100. They identify disproportionate moves when an index breaks a 100 multiple barrier. Recent research uses neural networks and hybrid models in an attempt to predict stock index levels (Ferreira, Vasconcelos and Adeodato, 2008).

Breen, Glosten and Jagannathan (1989) forecast stock index excess returns. Their evidence shows one-month interest rates forecast the sign and variance of stock index excess returns. Martens, van Dijk and de Potter (2009) find incorporating macroeconomic effects into their prediction model improved out-of-sample forecast accuracy for twenty-day-ahead S&P 500 Index volatility forecasts.

If incorrectly priced, index options and futures produce arbitrage opportunities. Taylor (2007) examines mispricing associated with futures and spot price differences. He finds S&P 500 arbitrageurs prefer middle-of-the-day trades. Hora and Jalbert (2006) examine distribution characteristics of the DJIA over a 100-year period. Based on index distribution properties identified, they propose a Black and Scholes option-pricing model derivation based on the Student t-distribution (Black and Scholes, 1973). Empirical results show the adjusted options valuation more accurately prices Down Jones Industrial Average index options than the Black and Scholes model.

A large body of literature examines stock index volatility. French and Roll (1986) find higher volatility when stock exchanges are open. Several articles relate volatility changes to macroeconomic variables including time varying volatility and financial leverage (Christie, 1982), expected stock return changes (Merton, 1980 and Bollerslev, Engle and Wooldridge 1988) and interest rates (Lauterbach, 1989).

Periodically, stock index components change. Mergers, bankruptcy and other corporate events necessitate these changes. Several authors examine the impacts of index additions and deletions. Findings show stock price increases for firms added to an index. Similarly, stock prices of firms deleted from an index decline (Shleifer, 1986, Beneish and Gardner, 1995). Some attribute index addition induced stock price increases to improved investor awareness and reduced price volatility (Liu 2011). Chen, Noronha and Singal (2006) find arbitrage activity around index changes exists. Their examination shows index change arbitrage results in a collective loss approaching $2.1 billion annually for index fund investors. Jankovskis (2002) finds a 1.2 percent annual downward bias in Russell 2000 Index returns due to rebalancing.

As noted earlier Jalbert (2012) first introduced currency value adjusted stock indices. He computes currency adjusted indices based on existing U.S. stock indices. His statistical analysis shows significant differences in unadjusted and adjusted index levels as well as daily and annual index returns. Unadjusted and adjusted index annual returns for the Dow Jones Industrial Average differ by as much as 18.211 percent. A comparison of return signs show differences on 12.99 percent of all trading days. Thus, the unadjusted index indicates a positive (negative) return, but the adjusted index indicates a negative (positive) return. He finds adjusted and unadjusted indices have different distribution properties. Regression results show currency value changes explain as much as 8.44 percent of total wealth changes.

Jalbert (2014) provides an extension of Jalbert (2012) by using a different dollar value measure. Jalbert (2014), provides similar results with one notable exception. Jalbert (2014) finds the currency value changes explain a larger portion of the adjusted index changes. The results indicate that currency value changes explain as much as 15 percent of adjusted index changes.

DATA AND METHODOLOGY

Data for each trading minute for eight U.S. Stock Indices and the U.S. Dollar Index were obtained from Pi Trading (Pi Trading, 2013). Pi Trading provides open, high, low and close information for each trading minute throughout the day. The data extends from August 5, 2001 through April 5, 2013. Index data were matched with Dollar Index data for each trading tick. The Dollar Index equals the value of a basket of six currencies used to estimate the U.S. dollar value. As noted earlier, the index started in March of 1973 with value of 100. Higher index levels imply a stronger dollar. Lower index levels imply a weaker dollar. Dollar Index values show considerable variation, ranging from 164.72 in February 1985 to 70.698 in March 2008. Some authors criticize the index because of the currencies used to develop the index and currency weightings (Koch, 2013). Despite these limitations, the index is widely quoted.

This paper analyzes Seven Stock Indices: The Dow Jones Industrial Average (DJIA), NASDAQ Composite (COMPX), NASDAQ 100 (NDX), S&P 500 (SPX), S&P 400 (MID), Russell 3000 (RUA), and Russell 1000 (RUI). The Philadelphia Housing Index (HGX) provides an index of real estate values. The indices examined were selected because they are widely reported and the availability of data for analysis.

Table 1, Panel A shows summary statistics of the data. For each index, as many as 65,006 stock and real estate index observations could not be matched with Dollar Index data. This occurred primarily due to different trading hours for the Dollar Index and Stock Exchanges. Data prior to December 31, 2001 were eliminated from the data to create full data years for analysis. The final dataset extends from December 31, 2001 through April 5, 2013. The datasets include as many as 1,036,037 observations for each index.

Table 1: Summary Statistics

Index	Symbol	Total Obs.	Eliminated Obs.	Observations Examined	High	Low	Mean	Std. Dev.
Panel A: Raw Indices								
Dow Jones Ind.	INDU	1,100,603	64,743	1,035,860	14,683.80	6,470.91	10,937.73	1,668.62
NASDAQ Comp.	COMPX	1,100,793	64,810	1,035,983	3,270.09	1,108.73	2,222.78	483.82
NASDAQ 100	NDX	1,101,073	65,006	1,036,067	2,878.02	795.25	1,771.91	482.30
S&P 500	SPX	1,099,725	64,683	1,035,042	1,576.03	666.79	1,191.69	192.10
S & P 400	MID	1,097,033	64,365	1,032,668	1,154.56	370.90	729.34	179.91
Phil. Housing	HGX	1,046,733	61,386	985,347	293.58	54.33	152.11	56.58
Russell 3000 RUA	RUA	1,099,728	64,891	1,034,837	936.53	384.41	691.22	119.53
Russell 1000 RUI	RUI	1,099,215	64,775	1,034,440	873.76	362.27	648.78	109.94
Dollar Index	DXY				120.37	71.15	85.51	10.11
Panel B: Dollar Index Adjust Indices								
Dow Jones Ind.	INDU				12,622.7	5,730.42	9,262.05	1198.66
NASDAQ Comp.	COMPX				2,712.87	1,122.97	1,869.14	319.15
NASDAQ 100	NDX				2,344.24	857.52	1,484.75	329.18
S&P 500	SPX				1,381.31	590.19	1,009.69	144.46
S & P 400	MID				957.82	352.32	610.97	117.18
Phil. Housing	HGX				262.32	48.22	128.71	51.35
Russell 3000 RUA	RUA				776.56	340.25	584.42	84.63
Russell 1000 RUI	RUI				730.32	320.65	548.82	79.01
Index	**Symbol**	**Skewness**	**Kurtosis**					
Panel A: Raw Indices								
Dow Jones Ind.	INDU	-0.0616	-0.7379					
NASDAQ Comp.	COMPX	-0.0577	-0.6140					
NASDAQ 100	NDX	0.4001	-0.5346					
S&P 500	SPX	-0.2103	-0.6848					
S & P 400	MID	-0.0399	-0.9309					
Phil. Housing	HGX	0.6133	-0.8005					
Russell 3000 RUA	RUA	-0.2105	-0.8108					
Russell 1000 RUI	RUI	-0.1959	-0.7798					
Dollar Index	DXY	1.4710	1.9848					

(Table 1 continued)

Panel B: Dollar Index Adjusted Indices			
Dow Jones Ind.	INDU	0.0171	0.0781
NASDAQ Comp.	COMPX	0.1238	-0.3639
NASDAQ 100	NDX	0.6788	-0.0866
S&P 500	SPX	-0.0299	-0.1693
S & P 400	MID	0.1524	-0.5495
Phil. Housing	HGX	0.6340	-0.6751
Russell 3000 RUA	RUA	-0.1099	-0.4486
Russell 1000 RUI	RUI	-0.0855	-0.3684

This table shows summary statistics for the data sample. The column labeled Total Obs. indicates the number of tick observations from August 8, 2001 through April 5, 2013. The column labeled Eliminated Obs. were those observations where stock index data were available, but Dollar Index data were not available. These observations were eliminated from further consideration. The column labeled Observations Examined indicates the number of observations used for analysis in the remainder of the paper. The columns labeled High, Low and Mean indicated the maximum, minimum and average index level over the time period examined. Panel A shows results for the raw series and the dollar index. Panel B shows results for the dollar adjusted series.

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Consider an index with level, RI_t at time t. Consider further a dollar value index with base level of 100 and current level, DI_t, at time *t*. Then a dollar index adjusted index, AI_t, at time *t* equals:

$$AI_t = \frac{RI_t}{DI_t} * 100 \tag{1}$$

To demonstrate the use of Equation 1, suppose a raw stock index level equals 1,000. The corresponding dollar index level equals 115. Then the adjusted index equals:

$$AI_t = \frac{1,000}{115} * 100 = 1,150$$

The adjusted index equals the raw index when the dollar index equals 100. The adjusted index exceeds the raw index when the dollar index exceeds 100. The adjusted index is lower than the raw index when the dollar index is less than 100. We calculate Equation 1 for open, high, low and closing values for each data tick observation. These values provide the basis for this research. Table 1, Panel B shows summary statistics of the adjusted closing index levels.   In each case, the raw series standard deviation exceeds the adjusted series standard deviation. This finding indicates currency value changes offset variation in the raw index series.

RESULTS

Next, we examine correlation between the raw and adjusted series. Table 2 shows the Pearson correlation statistics. With the exception of the Philadelphia Housing Index, the results show negative correlation between each adjusted indexes and the Dollar Index. Correlation ranges between 0.1818 for the Philadelphia Housing Index and -0.6882 for the Standard and Poor's 400 Index. Correlation between the raw and adjusted indexes ranges from 0.7073 for the Dow Jones Industrial Average and 0.9831 for the NASDAQ 100. These negative correlation results suggest movement in the Dollar Index offset changes in the raw index. This variance in the adjusted index relative to the raw index.

Table 2: Correlation Analysis

Index	Symbol	Dollar Index	Raw and Adjusted Series
Dow Jones Industrial	INDU	-0.5423	0.7037
NASDAQ Composite	COMPX	-0.6488	0.8912
NASDAQ 100	NDX	-0.6268	0.9831
S&P 500	SPX	-0.4964	0.7430
S & P 400	MID	-0.6882	0.9327
Philadelphia Housing	HGX	0.1818	0.9809
Russell 3000 RUA	RUA	-0.5517	0.7837
Russell 1000 RUI	RUI	-0.5367	0.7712

This table shows correlation coefficients between the raw index, the Dollar Index and the adjusted series levels. The column labeled dollar index shows the correlation between the dollar index and the currency adjusted index. The column labeled Raw and Adjusted Series shows correlation levels between the unadjusted and dollar index adjusted indexes.

We continue with an examination of differences between the high, H_t, and low, L_t, index values for each trading tick. We compute the spread between high and low index levels, SHL_t, for each tick as follows:

$$SHL_t = H_t - L_t \tag{2}$$

Table 3 shows the spread analysis results. The set of columns, titled Raw Spread, show statistics for the high and low value spread at each trading tick for the raw index. The second set of columns, titled Adj. Spread, shows statistics for high and low value spread at each tick for the Dollar Index adjusted index. The third set of columns shows differences between the raw and adjusted spreads. The t-test for mean differences, conducted assuming unequal variance, compares the Dollar Index adjusted and Raw Index spreads. The results show significant mean spread differences for each series. With the exception of the Philadelphia housing index, mean raw index spreads significantly exceed adjusted index spreads. This suggests that dollar index adjusting the indices decreases intra-tick spread variation. The F-test formally examines the variance differences of the two spreads. The results indicate significantly different spread variations.

Next, we compare the open, high, low and closing index levels for each tick. For each observation we compute four intra tick spreads. Consider a tick observation with opening value, O_t, closing value, C_t, and high and low values as previously defined. Equation 3 shows the Open-High spread, SOH_t, calculations. Equation 4, 5 and 6 show the Open-Low, SOL_t, Close-High, SCH_t, and Close-Low, SCL_t calculations respectively.

$$SOH_t = O_t - H_t \tag{3}$$

$$SOL_t = O_t - L_t \tag{4}$$

$$SCH_t = C_t - H_t \tag{5}$$

$$SCL_t = C_t - L_t \tag{6}$$

Table 3: Intra Tick Spread Analysis

Index	Raw Spread		Adj. Spread		Spread Difference		T-test for Mean Difference	F-Test for Variance Difference
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.		
Dow Jones Ind	4.6001	5.0227	3.8858	4.1906	-0.7143	1.0883	-44.64***	1.465***
NASDAQ Comp	0.7216	0.7329	0.6081	0.6060	-0.1136	0.1655	-948.8***	1.463***
NASDAQ 100	0.7735	0.7498	0.6534	0.6286	-0.1201	0.1711	-915.4***	1.423***
S&P 500	0.3437	0.4217	0.2889	0.3465	-0.0548	0.0904	-1,762***	1.481***
S&P 400	0.1657	0.2484	0.1359	0.6131	-0.0298	0.5821	-1,490***	0.1642***
Phil. Housing	0.0877	0.0937	0.0724	0.0761	-0.0153	0.0194	1.645***	1.516***
Russell 3000	0.1830	0.2203	0.1533	0.1801	-0.0297	0.0478	-3,468***	1.497***
Russell 1000	0.1794	0.2121	0.1506	0.1738	-0.0289	0.0460	-3,603***	1.489***

This table shows an analysis of index tick data. The set of column titled Raw Spread shows statistics for the raw index difference between the high and low values at each trading tick. The second set of columns shows statistics for the Dollar Index adjusted index difference between the high and low levels for each tick. The third set of columns shows the difference between the raw and adjusted spreads. The t-test for mean differences compares the Dollar Index adjusted and raw index spreads. The F-test examines the variance differences of the two spreads. Finally, the last column reports the absolute value of the spread difference.*** indicates significance at the one percent level.

We use these calculations to assess distribution symmetry. To the extent that differences between the open and low equal differences between the close and low the intra tick distribution displays symmetry around the low level. Similar computations can be made for the Intra Tick high. Table 4 shows the results. The adjusted index spreads are narrower than the raw index spreads for each index and each spread measure. The spreads generally show symmetry between open-high differences and open-low differences. But, there exist some departures from symmetry. We use the Dow Jones Industrial Average, raw index, results to demonstrate. The open and high index level spread equals 3.871. The close and high index levels spread equals 3.790. For the Open-High raw spread, the minimum value equals -326.16. For the Close-High spread the minimum value equals -241.68. Given the large number of observations examined in this study, these finding suggest considerable departure from symmetry.

Next, we explore the explanatory power of adjusted index components. We begin by examining index levels. This analysis involves three ordinary least squares regression analysis. We use regression analysis to determine the amount of variation in the adjusted index explained by the Dollar Index and the unadjusted index. The first regression determines the proportion of variation in adjusted index levels attributable to the raw stock index. The second regression determines the proportion of variation in adjusted index levels attributable to variation in the Dollar Index. The third regression determines the proportion of adjusted index level variation explained by the combined effects of raw index and Dollar Index changes. Equations 7, 8 and 9 show the specifications for each regression respectively.

$$AI_t = \alpha + \beta_1 RI_t + \varepsilon_t \qquad (7)$$

$$AI_t = \alpha + \beta_1 DI_t + \varepsilon_t \qquad (8)$$

$$AI_t = \alpha + \beta_1 RI_t + \beta_2 DI_t + \varepsilon_t \qquad (9)$$

Table 4: Intra Tick Variance Analysis

		Raw				Adjusted			
	N	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Panel A: Dow Jones Industrial Average									
Open – High	1,035,860	-2.307	3.871	-326.16	0	-1.949	3.225	-264.71	0
Open – Low	1,035,860	2.293	3.884	0.00	244.52	1.937	3.234	0	187.40
Close – High	1,035,860	-2.301	3.790	-241.68	0	-1.944	3.160	-185.22	0
Close – Low	1,035,860	2.299	3.769	0.00	319.39	1.942	3.144	0	259.22
Panel B: NASDAQ Composite									
Open - High	1,035,983	-0.3609	0.5952	-79.44	0.00	-0.3041	0.4963	-62.21	0.00
Open - Low	1,035,983	0.3607	0.5986	0.00	38.96	0.3040	0.4988	0.00	30.24
Close - High	1,035,983	-0.3608	0.5875	-38.96	0.00	-0.3041	0.4900	-30.24	0.00
Close - Low	1,035,983	0.3609	0.5877	0.00	79.44	0.3040	0.4903	0.00	62.21
Panel C: NASDAQ 100									
Open - High	1,036,067	-0.3866	0.6076	-32.60	0.00	-0.3266	0.5132	-27.76	0.00
Open – Low	1,036,067	0.3869	0.6168	0.00	41.38	0.3268	0.5199	0.00	35.19
Close - High	1,036,067	-0.3867	0.6016	-37.90	0.00	-0.3268	0.5080	-32.23	0.00
Close - Low	1,036,067	0.3868	0.5978	0.00	32.35	0.3267	0.5054	0.00	27.54
Panel D: S&P 500									
Open - High	1,035,042	-0.1721	0.3324	-0.1781	0.00	-0.1447	0.2749	-14.04	0.00
Open - Low	1,035,042	0.1715	0.3341	0.00	24.58	0.1442	0.2764	0.00	19.08
Close - High	1,035,042	-0.1719	0.3310	-24.58	0.00	-0.1445	0.2740	-19.08	0.00
Close - Low	1,035,042	0.1788	0.3284	0.00	17.81	0.1445	0.2718	0.00	14.04
Panel E: S&P 400									
Open - High	1,032,668	-0.0831	0.1900	-10.06	0.00	-0.0685	0.1533	-9.298	0.00
Open - Low	1,032,668	0.0825	0.1924	0.00	13.26	0.06799	0.1553	0.00	11.31
Close - High	1,032,668	-0.0825	0.1913	-12.02	0.00	-0.0680	0.01544	-10.25	0.00
Close - Low	1,032,668	0.08311	0.1896	0.00	10.06	0.06844	0.1530	0.00	8.298
Panel F: Philadelphia Housing									
Open - High	985,347	-0.0438	0.0740	-4.490	0.00	-0.0362	0.0605	-3.548	0.00
Open - Low	985,347	0.0438	0.0720	0.00	2.360	0.0362	0.0589	0.00	1.900
Close - High	985,347	-0.0439	0.0714	-2.360	0.00	-0.0362	0.0584	-1.923	0.00
Close - Low	985,347	0.0438	0.0729	0.00	4.450	0.0361	0.0596	0.00	3.548
Panel G: Russell 3000									
Open - High	1,034,837	-0.0916	0.1750	-15.45	0.00	-0.0767	0.1440	-12.54	0.00
Open - Low	1,034,837	0.0914	0.1756	0.00	9.99	0.0766	0.1446	0.00	7.649
Close - High	1,034,837	-0.0916	0.1740	-9.99	0.00	-0.0767	0.1434	-7.649	0.00
Close - Low	1,034,837	0.0915	0.1734	0.00	15.45	0.0766	0.1427	0.00	12.54
Panel H: Russell 1000 RUI									
Open - High	1,034,440	-0.0899	0.1689	-14.82	0.00	-0.0754	0.1394	-12.03	0.00
Open - Low	1,034,440	0.08960	0.1695	0.00	9.45	0.7519	0.1399	0.00	7.236
Close - High	1,034,440	-0.0897	0.1677	-9.45	0.00	-0.0753	0.1386	-7.236	0.00
Close - Low	1,034,440	0.08975	0.1673	0.00	14.82	0.0753	0.1382	0.00	12.03

This table shows an analysis of the intra tick spread. Open-High indicates the opening index level minus the high index level. Open-Low indicates the opening index level minus the low index level. Close – High indicates the closing index level minus the high index level. Close-Low indicates the closing index level minus the low index level.

Table 5 shows the regression results. The results show the independent variables significantly explain the dependent variable for each regression. This finding is not surprising given the methodology used to create the adjusted indices. The unadjusted stock index change and multiple regression analysis produces positive independent variable coefficient in each regression. The Dollar Index change coefficients show mixed signs. Five Dollar Index regressions have positive coefficients and three negative coefficients. Of primary interest is the R^2 value for each regression. For the unadjusted stock index regression, the R^2 varies from 0.4952 for the Dow Jones Industrial Average to 0.9621 for the Philadelphia Housing Index. This finding indicates unadjusted index levels explain as little as 49.52 percent of adjusted index levels. The dollar index change reveals R^2 statistics ranging from 0.0062 to 0.1532. The findings indicate Dollar Index levels explain as much as 15.32 percent of adjusted index levels. The multiple regressions produce R^2 statistics of 0.9872 and above.

Table 5: Regression Analysis on Dollar Index Adjusted Return Indices Levels

Dependent Variable	Intercept	Unadjusted Stock Index Levels	T-statistic	Intercept	Dollar Index Levels	T-statistic	R2
Panel A: Single Regression for Unadjusted Stock Index Levels							
Dow Jones Industrial	3,732.99	0.5055	1,008***				0.4952
NASDA Composite	562.46	0.5879	1,999***				0.7942
NASDAQ 100	350.22	0.6403	2,757***				0.8800
S&P 500	343.69	0.5587	1,130***				0.5521
S&P 400	167.90	0.6075	2,628***				0.8700
Philadelphia Housing	-0.6701	0.8902	5,001***				0.9621
Russell 3000	200.89	0.5549	1,284***				0.6142
Russell 1000	189.24	0.5542	1,232***				0.5948
Panel B: Single Regression for Dollar Index Levels`							
Dow Jones Industrial				7,135	24.870	218.5***	0.0440
NASDAQ Composite				2,527	-7.692	-255.9***	0.0595
NASDAQ 100				2,400	-10.706	-354.7***	0.1083
S&P 500				758.3	2.939	214.1***	0.0424
S&P 400				999.0	-4.539	-432.3***	0.1532
Philadelphia Housing				-70.37	2.368	387.9***	0.1325
Russell 3000				528.2	0.6574	80.1***	0.0062
Russell 1000				471.0	0.9093	119.5***	0.0135
Panel C: Multiple Regression							
Dow Jones Industrial	-8,326.37	0.8318	10,261***		99.28	7,424***	0.9907
NASDAQ Composite	-1,544.18	0.8349	8,666***		18.21	3,953***	0.9872
NASDAQ 100	-1,159.60	0.8227	9,811***		13.87	3,471***	0.9905
S&P 500	-926.56	10.887	6,849***		0.8424	10,074***	0.9903
S&P 400	-459.14	0.8207	8,887***		5.516	3,355***	0.9891
Philadelphia Housing	-106.90	0.8585	19,366***		1.249	3,930***	0.9977
Russell 3000	-523.15	0.8417	9,829***		6.148	6,072***	0.9895
Russell 1000	-494.79	5.820	6,312***		0.8415	9,924***	0.9897

This table shows regression results for Equations 7, 8 and 9 which related to index levels. Panel A reports estimation results for Equation 7, specified: $AI_t = \alpha + \beta_1 RI_t + \varepsilon_t$. AI indicates the dollar adjusted stock index. RI indicates the original index. Panel B reports estimation results for Equation 8, specified: $AI_t = \alpha + \beta_1 DI_t + \varepsilon_t$. DI indicates the Dollar Index. Panel C reports estimation results for Equation 9, specified: $AI_t = \alpha + \beta_1 RI_t + \beta_2 DI_t + \varepsilon_t$. *** indicates significance at the 1 percent level.

To further examine the relationship between raw index levels and adjusted index levels, we examine how changes in raw index levels relate adjusted index changes. To complete the analysis we estimate the regressions depicted in equations 10-12.

$$AI_t - AI_{t-1} = \alpha + \beta_1(RI_t - RI_{t-1}) + \varepsilon_t \tag{10}$$

$$AI_t - AI_t = \alpha + \beta_1(DI_t - DI_{t-1}) + \varepsilon_t \tag{11}$$

$$AI_t - AI_{t-1} = \alpha + \beta_1(RI_t - RI_{t-1}) + \beta_2(DI_t - DI_{t-1}) + \varepsilon_t \tag{12}$$

The results presented in Table 6 correspond to those presented in Table 5. Similar to the results in Table 5, in each regression the coefficients are significant. Panel A shows R2 statistics for unadjusted stock index changes range from 0.6893 to 0.9339. Panel B shows R2 statistics for the dollar index change range from 0.0144 to 0.1541. Panel C shows multiple regression results. The multiple regression R2 statistics range from 0.9729 to 0.9853.

Next, we examine Dollar Index adjusted index returns. To complete the analysis we estimate the regressions depicted in equations 13-14.

$$\ln\left(\frac{AI_t}{AI_{t-1}}\right) = \alpha + \beta_1 \ln\left(\frac{RI_t}{RI_{t-1}}\right) + \varepsilon_t \tag{13}$$

$$\ln\left(\frac{AI_t}{AI_{t-1}}\right) = \alpha + \beta_1 \ln\left(\frac{DI_t}{DI_{t-1}}\right) + \varepsilon_t \tag{14}$$

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Table 6: Regression Analysis on Dollar Index Adjusted Indices Changes

Dependent Variable	Intercept	Unadjusted Stock Index Change	T-statistic	Intercept	Dollar Index Change	T-statistic	R2
Panel A: Single Regression for Unadjusted Stock Index Change							
Dow Jones Industrial	-0.00319	0.7734	1,696***				0.7353
NASDAQ Composite	-0.00057	0.7621	1,873***				0.7719
NASDAQ 100	-0.00048	0.7883	2,216***				0.8258
S&P 500	-0.00036	0.7684	1,662***				0.7273
S&P 400	-0.00011	0.7211	1,514***				0.6893
Philadelphia Housing	-0.00003	0.8207	3,731***				0.9339
Russell 3000	-0.00019	0.7506	1,568***				0.7037
Russell 1000	-0.00019	0.7573	1,600***				0.7123
Panel B: Single Regression for Dollar Index Change							
Dow Jones Industrial				0.00290	78.489	411.6***	0.1405
NASDAQ Composite				0.0008	14.349	333.7***	0.0970
NASDAQ 100				0.00081	11,445	276.7***	0.0688
S&P 500				0.00022	8.4687	417.4***	0.1441
S&P 400				0.00048	4.8099	473.7***	0.1541
Philadelphia Housing				0.00002	0.7593	120.2***	0.0144
Russell 3000				0.00018	4.7863	431.1***	0.1522
Russell 1000				0.00015	4.5317	425.8***	0.1491
Panel C: Multiple Regression							
Dow Jones Industrial	0.00012	0.8363	7,365***		105.39	3,999***	0.9839
NASDAQ Composite	0.00005	0.8238	6,326***		21.126	3,055***	0.9772
NASDAQ 100	0.00003	0.8318	5,876***		16.872	2,370***	0.9729
S&P 500	-0.00006	0.8339	7,229***		11.405	3,993***	0.9834
S&P 400	0.00007	0.7976	5,858***		6.6406	3,457***	0.9753
Philadelphia Housing	0.00001	0.8418	8,073***		1.441	1,858***	0.9853
Russell 3000	0.000007	0.8255	6,999***		6.5577	4,056***	0.9825
Russell 1000	0.000003	0.8287	7,054***		6.1731	4,017***	0.9827

This table shows regression results for Equations 10, 11 and 12. Panel A reports estimation results for Equation 10, specified: $AI_t - AI_{t-1} = \alpha + \beta_1(RI_t - RI_{t-1}) + \varepsilon_t$. AI indicates the dollar adjusted stock index. RI indicates the original index. Panel B reports estimation results for Equation 11, specified: $AI_t - AI_t = \alpha + \beta_1(DI_t - DI_{t-1}) + \varepsilon_t$. DI indicates the Dollar Index. Panel C reports estimation results for Equation 12, specified: $AI_t - AI_{t-1} = \alpha + \beta_1(RI_t - RI_{t-1}) + \beta_2(DI_t - DI_{t-1}) + \varepsilon_t$. *** indicates significance at the 1 percent level.

Table 7 shows the results. Again, the results show significant regression coefficients for each regression. Panel A shows R2 statistics for the unadjusted stock index returns range between 0.7262 and 0.9561. Panel B shows R2 statistics for the Dollar Index change range from 0.0023 to 0.1439. We do not present multiple regression results because the combined unadjusted stock index return and dollar index return create a linear combination and thus are not suitable for regression analysis.

Combined, the results show the Dollar Index explains between 0.23 and 15.41 percent of adjusted index levels, changes and returns. The unadjusted index explains between 49.52 percent and 96.21 percent of adjusted levels, changes and returns. For each regression, the coefficients are significant at the one percent level. The results here are consistent with the results of Jalbert (2014) who also used Dollar Index data, but who analyzed only close-of-day data.

CONCLUDING COMMENTS

This paper examines new stock indexes which incorporate both traditional stock indexes and changes in the underlying currency value. This paper extends the extant literature by examining intraday data spanning the time period 2002-2013. Previous studies examine only daily closing data. This study provides a more detailed analysis of the impact of currency value adjusting indexes.

The results show negative correlation between the adjusted stock index and Dollar Index. Moreover, currency adjusted indices display lower volatility than raw indexes. Combined, these results suggest that raw indexes overestimate the volatility of wealth changes. The results show intra tick deviations from symmetry about the intra tick high and low values. Finally, results show that Dollar Index levels explain as much as 15.32 percent of wealth levels when the intercept is included in the regression. The results further show that Dollar Index changes explain as much as 15.41 percent of wealth changes.

The combined results clearly indicate the importance and value of currency adjusted indices. Individuals can gain added insights into the relative performance of their investments by examining currency adjusted indices. Asset pricing models based on unadjusted stock indexes overestimate market risk. Asset pricing models that have found little empirical support might produce better results when examined using currency adjusted indices.

There exists significant opportunity for research in this area. This study is limited to raw index levels which do not take into account dividends. Future work might examine dividend adjusted index levels to gain additional insights. This study is also limited to U.S. based indexes. However, stock indexes exist in many other countries. Future work might currency adjust indexes from other countries.

Table 7: Regression Analysis on Dollar Index Adjusted Returns

Dependent Variable	Intercept	Unadjusted Stock Index Returns	T-statistic	Intercept	Dollar Index Returns	T-statistic	R2
Panel A: Single Regression for Unadjusted Stock Index Returns							
Dow Jones Industrial	<0.00001	0.9237	1,884***				0.7740
NASDAQ Composite	<0.00001	0.9352	2,155***				0.8176
NASDAQ 100	<0.00001	0.9631	2,702***				0.8757
S&P 500	<0.00001	0.9189	1,859***				0.7696
S&P 400	<0.00001	0.9090	1,653***				0.7262
Philadelphia Housing	<0.00001	0.9659	4,634***				0.9561
Russell 3000	<0.00001	0.9087	1,751***				0.7476
Russell 1000	<0.00001	0.9128	1,792***				0.7564
Panel B: Single Regression for Dollar Index Returns							
Dow Jones Industrial				<0.00001	0.7005	364.17***	0.1135
NASDAQ Composite				<0.00001	0.6746	309.81***	0.0848
NASDAQ 100				<0.00001	0.7227	269.67***	0.0656
S&P 500				<0.00001	0.6873	360.70***	0.1117
S&P 400				<0.00001	0.7155	416.63***	0.1439
Philadelphia Housing				<0.00001	0.2235	47.16***	0.0023
Russell 3000				<0.00001	0.6820	377.24***	0.1209
Russell 1000				<0.00001	0.6840	370.54***	0.1172

This table shows regression results for Equations 13 and 14. Panel A reports estimation results for Equation 13, specified: $\ln\left(\frac{AI_t}{AI_{t-1}}\right) = \alpha + \beta_1\ln\left(\frac{RI_t}{RI_{t-1}}\right) + \varepsilon_t$. AI indicates the dollar adjusted stock index. RI indicates the original index. Panel B reports estimation results for Equation 14, specified: $\ln\left(\frac{AI_t}{AI_{t-1}}\right) = \alpha + \beta_1\ln\left(\frac{DI_t}{DI_{t-1}}\right) + \varepsilon_t$. DI indicates the Dollar Index. *** indicates significance at the 1 percent level.

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