**Does social-media sentiment predict stock returns? Evidence from Twitter**

**Author:** Dr. Konpanas Dumrongwong

**Affiliation:** Department of Finance, Thammasat University, Bangkok, Thailand

**Corresponding Author:** Dr. Konpanas Dumrongwong

**Email address:** konpanas@tbs.tu.ac.th

**Address of corresponding author:** Konpanas Dumrongwong, 2 Phra Chan Alley, Phra Borom Maha Ratchawang, Phra Nakhon, Bangkok, 10200, Thailand.

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**Abstract**

 Using a novel Twitter-based investor sentiment index, this research investigates whether investor sentiment, as expressed in daily Twitter messages, has predictive power with respect to U.S. stock returns. Based on a conventional linear framework, the empirical results show that the Twitter sentiment index does have additional predictive power for U.S. stock returns, which is not captured by traditional factors, such as market risk premium, firm size, book-to-market ratio, or momentum.

**Keywords**: behavioral finance, Twitter, investor sentiment, empirical asset pricing

**JEL Classification**: G12, G40

**1. Introduction**

 Financial scholars have long debated about the possible effects of investor sentiment on asset prices. Traditional theoretical asset pricing models, such as the capital asset pricing model (CAPM), are generally unreliable in explaining changes in real-world stock returns and pose many challenges in practical application. Many versions of empirical asset pricing models exist and some of them are arguably better at explaining realized equity returns. Good examples include the famous Fama-French three-factor model (Fama and French, 1993), the Carhart four-factor model (Carhart, 1997) and the Fama-French five-factor model (Fama and French, 2015). Although these models are more successful at explaining equity returns, it is still unclear what risk (or risks) the empirical factors truly account for in these models. For example, what are the actual risk factors of a book-to-market (B/M) ratio (i.e., the ratio of the book value of a common stock to its market value)? Similar arguments apply to other empirical factors, such as firm size or momentum. Therefore, it remains inconclusive whether these recognized factors are the only ones relevant to stock returns, or whether there are other unknown factor(s) with additional predictive power.

 As the search for a better empirical model continues, academic focus has shifted away from relying on the rationality assumption and has begun investigating the relationships between asset prices and investor sentiment. Noise traders and psychological biases are primary subjects in analyses of the impact of investor sentiment on stock prices. For example, De Long et al. (1990) have shown that irrational noise trader behavior cannot be offset by limited arbitrageurs, and that a wide spectrum of sentiment from diverse investors could affect stock prices and result in higher expected returns. However, since it is not possible to directly observe investor sentiment without an intrusive survey, many studies have relied on indirect proxies, such as closed-end fund discounts (Lee et al., 1991), bid-ask spreads and turnover (Baker and Stein, 2004), consumer confidence (Lemmon and Portniaguina, 2006; Schmeling, 2009) or a combination of all of these (Baker and Wurgler, 2006). Although these traditional measures of investor sentiment provide some useful insights into the relationship between asset prices and investor sentiment, they have their disadvantages. For example, market-based proxies may be affected by many confounding variables, and survey-based proxies cannot guarantee response quality.

The present research offers new insights into the issue of investor rationality by applying new data and techniques, employing a direct online measure of investor sentiment rather than relying on indirect proxies. This measure, observed passively, allows for a direct estimate of investor sentiment while minimizing the problem of response quality. This paper’s contribution is original in two ways. First, this research employs a novel proxy for investor sentiment constructed from Twitter, which has the advantage of avoiding endogeneity and directly capturing high-frequency investor sentiment. Unlike survey-based proxies, online-search-based measures *reveal* attitudes rather than *inquire* about them. Consequently, the measure is less prone to biases than are survey-based measures of sentiment. Second, the empirical results presented in this study are consistent with recent empirical theories that an investor sentiment index constructed from social media has predictive power with respect to U.S. stock returns. This predictive power has not previously been explained in the finance literature by popular risk factors, such as market risk premium, firm size, B/M ratio, or momentum.

 The remainder of the paper is structured as follows. The next section presents a review of the literature regarding investor sentiment and its implications for stock returns. The following section describes the research hypotheses, data, and methodology. The empirical results are then presented and discussed. Finally, conclusions are presented, along with research limitations and suggestions for future research.

**2. Literature Review**

 Traditional risk-based asset pricing models, such as the capital asset pricing model (CAPM) are based on the premise that prices reflect the consensus investor’s expectation of risks associated with his or her investment; such models assume the existence of a theoretical market portfolio, which is unobservable and perfectly diversified (for the theoretical underpinnings, see Markowitz, 1952; Sharpe, 1964; Lintner, 1965; Fama, 1970; and Black, 1972). However, the practicality of the CAPM is highly debatable because it requires many rigid assumptions. For example, all investors are expected to be rational, and the informational efficiency of both market and investors must be perfect. In practice, it is very challenging to reconcile these unrealistic conditions in real-world applications.

Many scholars strongly dispute the validity of the CAPM. Indeed, a number of empirical studies have identified the existence of trends in stock returns as well as model limitations, contradicting the CAPM prediction. For example, Banz (1981) documented that when stocks are sorted according to market capitalization, average returns on small stocks are higher than predicted by the CAPM. Stambaugh (1982) argued that the tests of the CAPM are not sensitive to expanding the market proxy beyond common stocks, which contradicts the definition of market portfolio in the CAPM. Rosenberg et al. (1985) showed that stocks with high B/M ratios have high average returns that are not captured by betas. These contradictory findings ultimately led Fama and French (2004) to conclude that “the failure of the CAPM in empirical tests implies that most applications of the model are invalid” (p. 26).

Some academics have proposed the idea of arbitrage-free equilibrium as an alternative model to the CAPM. Ross (1976), among others, developed the arbitrage pricing theory (APT), with each investor holding a unique portfolio with its own particular array of betas, as opposed to the identical market portfolio required in CAPM. In addition, according to the APT, although some investors may not be rational, their irrationalities should be offset quickly by arbitrageurs. However, behavioral finance theory consistently suggests that the presence of noise traders in the stock market, with associated behavior, as well as limits on arbitrage, are restricting conditions that can lead investor sentiment to influence asset prices (e.g., Shleifer and Summers, 1990; Lee et al. 1991; Shleifer and Vishny, 1997; Baker and Wurgler, 2006). De Long et al. (1990), notably, modelled the influence of noise trading on equilibrium prices and showed that noise trading affects stock prices and that noise traders can earn higher expected returns. Shleifer and Vishny (1997) demonstrated that there are limits on risky arbitrage positions which can cause changes in security prices. Furthermore, Baker and Wurgler (2006) documented that investor sentiment contains functional predictive content about stock returns.

For decades, stock market prediction has been the subject of intense debates among academics, and yet a determination of the true set of drivers behind stock returns remains elusive. An important aspect of the debate is the question of whether investor sentiment predicts stock returns. Several theoretical studies offer various behavioral-based models establishing the link between asset prices and investor sentiment. For example, it has been documented that investors may form erroneous beliefs, through either excessive optimism or pessimism, and may therefore incorrectly evaluate asset values, causing asset price movements (e.g., Black, 1986; De Long et al., 1990; Daniel et al., 1998; Baker et al., 2012).

Baker and Wurgler (2007) showed that investor sentiment predictive content in relation to future market movements can act as valuable information for traders in formulating profitable trading strategies. They broadly defined investor sentiment as “investors’ belief about future cash flows and risk not justified by the facts at hand” and noted that, “Now, the question is no longer, as it was a few decades ago, whether investor sentiment affects stock prices, but rather how to measure investor sentiment and quantify its effects.” (p.130). The present research employs these definitions and extends the analysis of the link between investor sentiment and stock returns, using new data and a new methodology for measuring sentiment.

A growing body of research has documented the relationship between investor sentiment and asset prices. For example, Baker et al. (2012) investigated stock prices in Canada, France, Germany, Japan, the United Kingdom, and the United States and found that sentiment is correlated with stock prices of listed companies in these major stock markets. Dergiades (2012) studied the U.S. stock indexes from 1965 to 2007 and showed that investor sentiment holds significant predictive power with respect to stock returns. And Kaplanski et al. (2015) used a survey to investigate sentiment among 900 investors and found that, on average, more positive investor sentiment is accompanied by higher return expectations and greater intentions to buy stocks. In their study, they also found that investor sentiment affects expected returns more intensely than does expected risk.

In this context, prior research has also revealed that online sources are known to contain information regarding investor sentiment, which is correlated with stock returns. For example, Siganos et al. (2014) examined investor sentiment as expressed in Facebook posts, and found that this sentiment has a positive contemporaneous association with stock returns, and that there exists a one-way causality from online sentiment to stock returns. Kim and Kim (2014) investigated investor sentiment as measured by Yahoo! Finance message board postings, and found that investor sentiment has predictive power for stock returns. Da et al*.* (2015) documented a sentiment index constructed from Google search volumes and showed a correlation between sentiment as expressed in Google searches and asset prices. They found that negative words expressed in Google searches correspond with low market returns on the same day. Finally, Zhang et al. (2018) studied daily Twitter-based sentiment from 2008 to 2017 and found that the Twitter-based sentiment index Granger-causes index returns in their linear causality test. These prior studies have provided an important foundation for the hypothesis in this research in three principal ways: first, they established the correlation between a social-media investor sentiment index and stock returns; second, they discovered one-way causality from social-media sentiment to stock returns; and, third, their findings implied that investor sentiment constructed from social-media should be a relevant factor for explaining stock returns.

Although prior evidence has established that social-media sentiment can cause stock return movement, it is unclear if this evidence offers any additional explanatory power regarding stock returns (for example, it is possible that the explanatory power of social media sentiment is already captured by well-known factors documented in the finance literature, such as market risk premium, firm size, B/M ratio, or momentum). Prior studies (e.g., Signanos et al., 2014; Da et al., 2015; Zhang et al., 2018) utilized causality tests and correlation tests while focusing solely on the relation between stock prices and investor sentiment. However, they ignored the correlation between online investor sentiment and the aforementioned well-known risk factors documented in the finance literature, which are consistently found to have predictive power with respect to stock returns and stock return expectations. Given prior discoveries by Zhang et al. (2018), who proved that a Twitter-based sentiment index Granger-causes index returns, and Kaplanski et al. (2015), who showed that investor sentiment can drive stock returns, there is a need to study the explanatory power of Twitter-based sentiment relative to the predictive power of known risk factors.

Accordingly, our main hypothesis is that since A) sentiment such as mood or happiness, as expressed in Twitter messages, is unlikely to be explained by systematic factors in popular asset pricing models, such as market-risk premium, firm size, or B/M ratio; and because B) prior research has consistently established that a Twitter-based sentiment index Granger-causes stock returns (e.g., Zhang et al., 2018); a Twitter-based sentiment index should have predictive power with respect to stock returns in addition to those systematic factors. Unlike prior research (e.g., Baker and Stein, 2004; Baker and Wurgler, 2006) which employed indirect proxies for investor sentiment, this study applies new techniques by utilizing a novel Twitter-based sentiment index. This measure provides unique advantages by allowing for a direct estimate of investor sentiment at high frequency, while minimizing the problem of response quality.

Given that this research also involves the investigation of asset prices, it is particularly important to consider not only the theoretical asset pricing model (CAPM), but also prior contributions in the field of empirical asset pricing. Notable among the empirical asset pricing models is research by Fama and French (1993) who proposed their Fama-French three-factor model. According to the authors, stock returns can be empirically explained by three factors: market risk premium, B/M ratio (High Minus Low: HML), and firm size (Small Minus Big: SMB). This model garnered much attention from academics, and several studies have extended the model by including additional factors. Notably, Carhart (1997) argued that momentum should also be an important factor for determining asset prices, and posited that asset prices can be explained empirically by four factors: momentum factor in addition to the three factors from Fama-French’s three-factor model. Moreover, Fama and French (2015) extended their own three-factor model, adding profitability and investment as additional factors. It is important to note that although many other versions of empirical asset pricing models exist, this research primarily focuses on the Fama-French three-factor model and the Carhart four-factor model because they are among the most widely known models in academia.

**3. Materials and Methods**

*3.1 Data*

 The Twitter happiness index was constructed from <http://hedonometer.org/index.html>, which is generated from Twitter’s Decahose API feed database of over 50 million daily twitter post observations. The daily index is formulated by scoring nearly 10,000 sentiment-related words found in the database. Each of these words are then scored on a nine-point scale of happiness: (1) sad, to (9) happy, following Dodds et al.’s (2011) methodology. Due to data availability, the study period ranges from September 2008 to January 2021. All daily risk factors (market risk premium, risk-free rate, HML and SMB measures) are observed from the French data library (French, 2021). All data sources accord with prior research (e.g., Zhang et al., 2016; Zhang et al., 2018), providing a reliable base for comparisons.

*3.2 Methodology and Hypotheses*

Prior studies have consistently established that online sentiment Granger-causes stock returns and that there is a linear relationship between a Twitter-based investor sentiment index and stock returns (e.g., Siganos et al., 2014; Zhang et al., 2016; Zhang et al., 2018). Therefore, the present study utilizes a conventional linear framework, based on prior research, to investigate this relationship. Accordingly, Twitter-based investor sentiment was treated as an independent variable in conventional linear regression, again consistent with prior research. Since Da et al. (2015) showed that daily negativity (or positivity) in online posts corresponds to low (high) market-level returns on the same day, the effect of Twitter-based sentiment toward stock returns is therefore assumed to be observable on the same day. The Standard & Poor’s 500 Index (S&P 500) and the Dow Jones Industrial Average Index (DJIA) were selected to represent the U.S. stock market because the former is one of the most commonly followed indexes, while the latter is the oldest U.S. stock index. Additional tests using Gibbons et al.’s (1989) methodologies (henceforth GRS) on U.S. portfolios (2x3 and 5x5 formed on size and B/M ratios) were also conducted and are reported in the robustness checks section.

As discussed previously, the main focus of investigation of this study was the predictive power of Twitter-based sentiment, in addition to the well-known factors documented in the finance literature. This involved testing for the significance of the coefficient (β) of the Twitter-based sentiment (DHt) in the following time-series models. It is important to note here that although GRS tests are commonly used for time-series regressions, the following equations were considered more relevant to the research questions, since they are capable of directly testing the relevance of DHt as an additional variable, rather than indirectly testing the magnitude of alpha. Nevertheless, GRS tests on 2x3 and 5x5 portfolios are briefly discussed in the robustness checks section (see also Fama and French, 2020 for an alternative method).

 (1)

 (2)

 (3)

where Rt represents the daily stock returns at the end of day *t*, DHt represents the Twitter-based sentiment index on day t, MRPt represents the market risk premium on day t, SMBt represents the size premium (Small Minus Big) on day t, HMLt represents the value premium (High Minus Low) on day t, UMDt represents the momentum factor on day t, Rft represents the risk-free rate, and αt represents the intercept of the regression.

Accordingly, the following two working hypothesizes were formulated:

***H1***: Twitter-based sentiment contains additional predictive power with respect to stock returns which is not explained by factors in the Fama-French three-factor model.

***H2***: Twitter-based sentiment contains additional predictive power with respect to stock returns, which is not explained by factors in the Carhart four-factor model.

The above hypotheses were employed because they involve investigating empirical factors from the Fama-French three-factor model and the Carhart four-factor model, which are among the most popular asset pricing models in the finance literature. Although none of these factors are related to CAPM, the main tests also included a test using CAPM to provide basic contextual material for the investigation. Kaplanski et al. (2015) noted that sentiment can drive stock return expectations. However, the expected returns at the time of writing Twitter messages cannot be precisely measured and therefore there is no testable hypothesis for CAPM. Tests for newer empirical models, such as Fama-French’s later five-factor model (Fama and French, 2015) and GRS tests on additional portfolios were also conducted, and are reported in the robustness checks section.

**4. Results**

 All considered time series were tested for being stationary using Augmented Dickey–Fuller (Dickey and Fuller, 1979) and Phillips–Perron (Phillips and Perron, 1988) methodologies (henceforth, ADF and PP, respectively). The null hypothesis of a unit root for all considered series was rejected at 1% significance level. Table 1 presents the summary statistics for stock returns, independent variables, and the happiness sentiment index, to give an overview of the data.

Table 1. Summary statistics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | mean | median | SD | ADF | PP |
| S&P 500 | 0.0003 | 0.0006 | 0.01 | -64.11\*\*\* | -64.25\*\*\* |
| DJIA | 0.0003 | 0.0006 | 0.01 | -21.14\*\*\* | -62.68\*\*\* |
| MRPt | 0.047 | 0.085 | 1.34 | -63.17\*\*\* | -63.38\*\*\* |
| SMBt | -0.002 | 0.000 | 0.63 | -57.80\*\*\* | -58.02\*\*\* |
| HMLt | -0.022 | -0.035 | 0.78 | -55.70\*\*\* | -55.93\*\*\* |
| UMDt | 0.003 | 0.050 | 1.06 | -50.00\*\*\* | -49.84\*\*\* |
| DHt | 1.794 | 1.794 | 0.01 | -4.89\*\*\* | -23.62\*\*\* |

 MRPt represents the market risk premium on day t; SMBt represents the size premium (Small Minus Big) on day t; HMLt represents the value premium (High Minus Low) on day t; UMDt represents the momentum factor on day t; DHt represents the Twitter-based sentiment index on day t; and \*,\*\*,\*\*\* represent statistical significance at the 1%, 5%, and 10% levels, respectively.

 Since investor sentiment (such as mood or happiness, expressed in Twitter messages) is unlikely to be explained by systematic factors, such as B/M ratio, firm size, or momentum, it was intuitively anticipated that the correlation between the aforementioned empirical factors and the Twitter-based sentiment index (DH) would be zero or near zero. The results in Table 2 indeed confirm this expectation and show that the Pearson correlation between Twitter-based sentiment (DH) and other explanatory variables is very low: size premium (SMB) shows the highest correlation with DH at a marginal magnitude r=0.03. This evidence is broadly supportive of the main hypothesis because it shows that Twitter-based sentiment is almost uncorrelated with the known empirical factors used in popular empirical asset pricing models. Therefore, if the explanatory power of DH with respect to stock returns exists, it is not likely to be captured by any known risk factors within the CAPM, Fama-French three-factor or Carhart four-factor models.

In terms of orthogonality, the value premium (HML) and momentum (UMD) show relatively high correlation at r=-0.62. However, it was not necessary to exclude either of these factors from the main analysis because they are empirically identified as relevant factors in accordance with prior empirical research (e.g., Fama and French, 1993; Carhart, 1997). In addition, Equations 1 and 2 naturally exclude the momentum factor (UMD), already giving a clear view of the results without the UMD.

Table 2. Pearson correlation matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | MRP | SMB | HML | UMD | DH |
| MRPt | 1.00 |  |  |  |  |
| SMBt | 0.23 | 1.00 |  |  |  |
| HMLt | 0.34 | 0.22 | 1.00 |  |  |
| UMDt | -0.30 | -0.21 | -0.62 | 1.00 |  |
| DHt  | 0.02 | 0.03 | 0.03 | -0.02 | 1.00 |

MRPt represents the market risk premium on day t; SMBt represents the size premium (Small Minus Big) on day t; HMLt represents the value premium (High Minus Low) on day t; UMDt represents the momentum factor on day t; and DHt represents the Twitter-based sentiment index on day t.

The primary subject of investigation involved examining the “relevance” of the DH factor in Equations (1)–(3). The results are presented in Tables 3, 4 and 5, showing the explanatory power of the Twitter-based sentiment index, in addition to the risk factors stated in the CAPM and the Fama-French three-factor and Carhart four-factor models, respectively.

Table 3. Regression results: additional explanatory power of Twitter-based sentiment in CAPM

|  |  |  |
| --- | --- | --- |
|  | S&P 500 | DJIA |
| MRPt  | 1.00(698.44\*\*\*) | 0.93(237.79\*\*\*) |
| DHt | 0.32(1.65\*) | 1.19(2.23\*\*) |
| Intercept | -0.59(-1.69\*) | -2.15(-2.24\*\*) |
|  |  |  |
| Adj. R2 | 0.99 | 0.95 |
| Durbin-Watson | 2.12 | 1.92 |

 MRPt represents the market risk premium on day t; DHt represents the Twitter-based sentiment index on day t; Intercept = the intercept of the regression; and \*,\*\*,\*\*\* represent statistical significance at the 1%, 5%, and 10% levels, respectively.

 Results presented in Table 3 reveal that investor sentiment, as expressed in daily Twitter messages, contains predictive power with respect to U.S. index returns. The coefficient of investor sentiment was found to be positive, and statistically significant at 5% and 10% significance for DJIA and S&P 500, respectively. The results are consistent with Da et al.’s (2015) conclusion that daily negativity (or positivity) in online posts corresponds to low (high) market-level returns on the same day. The other factor (market risk premium, MRP) was found to be positive and statistically significant at 1%. These results were anticipated, as they are consistent with CAPM prediction. The Durbin-Watson statistic was found to be very close to 2, suggesting no evidence of autocorrelation in the considered cases.

It is important to note here that the CAPM results are provided only to more clearly illustrate the framework of this study. However, theoretically it can be argued that CAPM is not an appropriate model for examining stock returns because it is a theoretical model for explaining equilibrium *expected* returns, not realized stock returns. The literature on empirical asset pricing models has consistently suggested that firm size, B/M ratio, and momentum are correlated with realized stock returns (e.g., Fama and French, 1993; Carhart, 1997). Therefore, additional tests using these empirical models are required before stating any inference regarding the hypotheses. Accordingly, tests using the Fama-French three-factor and Carhart four-factor models were conducted and the results are presented in Table 4 and Table 5.

Table 4. Additional explanatory power of Twitter-based sentiment in the Fama-French three-factor model

|  |  |  |
| --- | --- | --- |
|  | S&P 500 | DJIA |
| MRPt | 1.00(952.76\*\*\*) | 0.93(236.79\*\*\*) |
| SMBt | -0.13(-58.30\*\*\*) | -0.16(-20.29\*\*\*) |
| HMLt | 0.03(16.12\*\*\*) | 0.07(10.96\*\*\*) |
| DHt | 0.47(3.52\*\*\*\*) | 1.31(2.62\*\*\*) |
| Intercept | -0.86(-3.58\*\*\*) | -2.36(-2.63\*\*\*) |
|  |  |  |
| Adj. R2 | 0.99 | 0.96 |
| Durbin-Watson | 1.95 | 1.91 |

 MRPt represents the market risk premium on day t; SMBt represents the size premium (Small Minus Big) on day t; HMLt represents the value premium (High Minus Low) on day t; DHt represents the Twitter-based sentiment index on day t; Intercept = the intercept of the regression; and \*,\*\*,\*\*\* represent statistical significance at the 1%, 5%, and 10% levels, respectively.

 Table 4 show results on Fama-French regressions with Twitter sentiment as an augmented variable. It was found that the coefficients of Twitter sentiment (DH) are statistically significant at 1% for all considered cases (S&P 500 and DJIA). This suggests that investor sentiment can drive stock returns, in line with Kaplanski et al*.*’s (2015) prediction. The signs of the coefficients were found to be positive, suggesting that higher sentiment expressed in Twitter is associated with higher returns, and vice versa. This finding is consistent with Da et al*.* (2015), who posited that daily negativity (or positivity) in online messages corresponds to low (high) market level returns on the same day.

The results for other factors accord with the findings of Fama and French (1993): market risk premium (MRP), size premium (SMB), and value premium (HML) were found to be significant predictors of stock returns. All coefficients of these factors are statistically significant at 1% significant level, consistent with Fama and French (1993). Since Twitter sentiment (DH) is a statistically significant factor in describing stock returns, and since its correlation with the other explanatory variables is marginal (as shown in Table 2), the results presented in Table 4 indicate that Twitter sentiment (DH) is a predictor for stock returns which cannot be explained by the market risk premium, firm size, or B/M ratio, confirming *H1*. Finally, the Durbin-Watson statistics were found to be very close to 2, suggesting no evidence of autocorrelation in all considered models.

Table 5. Additional explanatory power of Twitter-based sentiment in the Carhart four-factor model

|  |  |  |
| --- | --- | --- |
|  | S&P 500 | DJIA |
| MRPt | 1.00(946.41\*\*\*) | 0.94(236.55\*\*\*) |
| SMBt | -0.13(-58.12\*\*\*) | -0.16(-20.09\*\*\*) |
| HMLt | 0.03(13.13\*\*\*) | 0.08(10.05\*\*\*) |
| UMDt | 0.00(-0.16) | 0.01(1.84\*) |
| DHt | 0.47(3.52\*\*\*) | 1.30(2.61\*\*\*) |
| Intercept | -0.86(-3.58\*\*\*) | -2.35(-2.63\*\*\*) |
|  |  |  |
| Adj. R2 | 0.99 | 0.99 |
| Durbin-Watson | 1.95 | 1.91 |

 MRPt represents the market risk premium on day t; SMBt represents the size premium (Small Minus Big) on day t; HMLt represents the value premium (High Minus Low) on day t; UMDt represents the momentum factor on day t;DHt represents the Twitter-based sentiment index on day t; Intercept = the intercept of the regression; and \*,\*\*,\*\*\* represent statistical significance at the 1%, 5%, and 10% levels, respectively.

 Table 5 presents the results from the Carhart four-factor regression model, with Twitter sentiment as an augmented variable. Once again, it was found that the coefficients of Twitter sentiment (DH) are positive and statistically significant at 1% for all considered U.S. stock indexes. These results suggest that investor sentiment, as expressed in Twitter messages, have significant predictive power with respect to U.S. stock returns in addition to the four factors (market risk premium, firm size, value premium, and momentum) presented in the Carhart four-factor model, confirming *H2*. Once again, the signs of the coefficients were found to be positive, supporting Da et al. (2015), who posited that daily negativity (or positivity) in online posts corresponds to low (high) market-level returns on the same day. Other factors (MRP, SMB and HML) were found to be significant predictors of stock returns, in line with and Fama and French (1993). All of the coefficients of the aforementioned factors are statistically significant at 1%. The coefficient of momentum (UMD) was found to be significant in explaining DJIA daily returns, albeit at a lower significance level of 10%. Finally, Durbin-Watson statistics were found to be very close to 2, suggesting no evidence of autocorrelation for all considered models.

 Overall, the results from all of the tests conducted confirmed the main hypotheses *H1 and H2 —* that investor sentiment, as expressed in Twitter daily messages, contains predictive power with respect to U.S. stock returns. These results are consistent with Kaplanski (2015), and also support prior research in the field (Signanos et al., 2014; Zhang et al., 2018) establishing that Twitter-based sentiment Granger-causes stock returns. All signs of the coefficients of Twitter sentiment in all considered cases were found to be positive and statistically significant at 1%, in line with Da et al.’s (2015) prediction. The results are consistent, too, with empirical theories that investor sentiment predicts stock returns (De Long et al., 1990; Baker and Wurgler, 2007; Baker et al., 2012; Zhang et al., 2018).

**5. Robustness Checks**

 Since some professionals and academics view the S&P 500 and DJIA indexes as representative of large-cap stocks, it is possible that firm size differences could be a source of bias. To rule out any potential bias toward large-cap stocks, additional tests were performed to investigate the Wilshire 5000, S&P Midcap 400, Russell 2000 and NASDAQ composite indexes. The first three of these additional indexes were chosen as some professionals consider them representative of the total U.S. stock market, mid-cap stocks, and small-cap stocks, respectively. The results confirm the initial findings that Twitter sentiment has significant predictive power with respect to stock returns, albeit with lower significance.

 This study also experimented with newer asset pricing models such as the Fama-French five-factor model (Fama and French, 2015). The results show no material difference from the main analysis, with similar significance. More importantly, to address concerns that the main models used in this research did not correspond to the usual approach in the literature regarding time-series data, additional GRS tests (Gibbons et al., 1989) were conducted on 2x3 and 5x5 portfolios formed on size and B/M ratios in order to compare the performance of the models including a Twitter sentiment index as an augmented variable with the performance of its traditional model counterparts. It was found that models including a Twitter sentiment index as an augmented variable show lower absolute alphas compared to those of the original models, for all cases (the Fama-French three-factor, Carhart four-factor, and Fama-French five-factor models on 2x3 and 5x5 portfolios). This suggests that the Twitter sentiment index has explanatory power for stock returns, which is consistent with the initial findings.

In summary, the robustness tests supported the initial findings from the main analysis that Twitter-based sentiment has additional explanatory power for U.S. stock returns. This finding is robust to changes in the asset pricing models used in the study (the Fama-French three-factor, Carhart four-factor, and Fama-French five-factor models), as well as changes in type of stocks (large, medium or small market-capitalization portfolios).

6. **Conclusions**

According to classical finance theory, investor sentiment does not play any role in stock prices, expected returns, or realized returns. Based on the behavioral framework documented in prior research, this paper provides evidence that contradicts that view. This study used a simple and straightforward model to show that Twitter sentiment index is able to explain deviations of U.S. stock returns from the “rigorous” model’s prediction. It was found that a direct survey measure of investor sentiment, as expressed in Daily Twitter messages, predicts stock returns on the same day, and that this measure has the ability to explain deviations from intrinsic values as predicted by popular asset pricing models. In all cases studied, the significance of the sentiment index was found to be significant and robust to changes in asset pricing models (the Fama-French three-factor, Carhart four-factor, or Fama-French five-factor models) and significant for all considered equity portfolios. In addition, the Twitter sentiment index was almost uncorrelated with popular risk factors, suggesting that the predictive power of Twitter sentiment index is unlikely to be captured by any known risk factors, such as market risk premium, firm size, B/M ratio or momentum.

At least two possible interpretations can be suggested for these findings. First, because the explanatory power of Twitter sentiment is not captured by known risk factors, a conservative interpretation would be that this study identified a new factor (or a new proxy for unknown risks) related to asset valuation. Another possible interpretation is that the measure of investor sentiment used in this study is actually reasonably accurate and is directly related to the level of stock prices, as documented in behavioral theories.

Regardless of the interpretation, the results consistently suggest that the employed sentiment variable actually forecasts daily market returns and helps to explain deviations from popular valuation models, which is consistent with prior research (e.g., De Long et al., 1990; Baker and Wurgler, 2007; Baker et al., 2012; Siganos et al.,2014; Kaplanski et al.,2015; Da et al*.*, 2015; Zhang et al., 2018). This finding has several important implications. First, the results support behavioral theories that predict that the irrational sentiments of investors do in fact affect asset price levels. Second, the findings suggest that asset pricing models should consider the possible role of investor sentiment. Beyond the world of scholarship, the practical implications for this research are clear. Market regulators and government officials should be aware of the potential for market biases or ‘‘irrationalities’’ caused by investor sentiment. Since the Twitter sentiment index and stock returns were found to be correlated, the results presented in this study infer that a sudden change in sentiment could translate into a large wealth shock with the potential to depress the stock market. Ultimately, individual investors and fund managers should be aware of the impact sentiment can have on both their own portfolios and fund managers’ investment strategies.

**6.1 Research Limitations and Possible Future Research**

One of the limitations of this study is that this research focuses primarily on U.S. stocks while ignoring emerging market stocks . This limitation arises from the lack of online sentiment data and social media user demographics on these stocks, mainly due to the limitations of natural language processing techniques for non-English languages. For example, current algorithms in artificial intelligence cannot correctly understand ambiguous words in Japanese and Chinese; hence, sentiment observations from non-anglophone investors are largely ignored due to this technological constraint. This research also systematically focused primarily on the U.S. stock market because, according to Twitter usage statistics (Kemp, 2020), by far the largest number of English Twitter users are from the United States. Accordingly, the exclusive focus on stock markets in the anglophone world, and the lack of attention to emerging markets, are recognized as limitations of this study and identified as promising areas for future research should the data become available.

Another minor topic worth mentioning is that the results from the present study do not distinguish between the effects on stock prices caused by volatility and those caused by investor sentiment. There are two main reasons for this. First, prior research has documented that investor sentiment is more relevant to returns than are risks. For example, Kaplanski et al. (2015) argued that investor sentiment affects expected returns more intensely than does expected risk. This position is also consistent with Da et al.’s (2015) position and broadly in line with recent research by Ding et al. (2019), who showed that the effect of sentiment on returns is not related to systematic risk. Second, it is plausible that certain risk factors may already be captured by the effects of volatility (for example, the market-risk premium tends to be higher during times of high volatility, and vice versa), making this issue less relevant to the present study.

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