Both Rates of Fake News and Fact-based News on Twitter Negatively Correlate with the State-level COVID-19 Vaccine Uptake

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Abstract

There is evidence of misinformation in the online discourses and discussions about the COVID-19 vaccines. Using a sample of 1.6 million geotagged English tweets and the data from the CDC COVID Data Tracker, we conduct a quantitative study to understand the influence of both misinformation and fact-based news on Twitter on the COVID-19 vaccine uptake in the U.S. from April 19 when U.S. adults were vaccine eligible to May 7, 2021, after controlling state-level factors such as demographics, education, and the pandemic severity. We identify the tweets related to either misinformation or fact-based news by analyzing the URLs. By analyzing the content of the most frequent tweets of these two groups, we find that their structures are similar, making it difficult for Twitter users to distinguish one from another by reading the text alone. The users who spread both fake news and fact-based news tend to show a negative attitude towards the vaccines. We further conduct the Fama-MacBeth regression with the Newey-West adjustment to examine the effect of fake-news-related and fact-related tweets on the vaccination rate, and find marginally negative correlations.

Introduction

A previous study (Wu, Lyu, and Luo[2021]) has found evidence of misinformation in the online discourses and discussions about the COVID-19 vaccines. Rzymski et al. [2021] suggested tracking and tackling emerging and circulating fake news. Montagni et al. [2021] argued to increase people’s ability to detect fake news. Marco-Franco et al. [2021] found that citizens do not support the involvement of government authorities in the direct control of news. Collaboration with the media and other organizations should be used instead. However, little is known about the scale and scope of the influence of misinformation and fact-based news about COVID-19 vaccines on social media platforms on the vaccine uptake. To summarize, this work (1) quantitatively analyzes the effect of fake news and fact-based news on the vaccine uptake in the U.S. using the Fama-MacBeth regression with the Newey-West adjustment and (2) compares the most frequent fake-news-related and fact-related tweets by conducting a content analysis.

Data Collection

Twitter Data

We use the Tweepy API[1] to collect the related tweets that are publicly available. The search keywords and hashtags are COVID-19 vaccine-related or vaccine-related, including “vaccine”, “COVID-19 vaccine”, “COVID vaccine”, “COVID19 vaccine”, “vaccinated”, “immunization”, “covidvaccine”, “vaccine” and “covid19vaccine”. Slang and misspellings of the related keywords are also included which are composed of “vaccine”, “vaccine”, “antivax” and “anti vax”. The tweets that are only related to other vaccine topics like MMR, autism, HPV, tuberculosis, tetanus, hepatitis B, flu shot or flu vaccine are removed. Moreover, since this study focuses on the tweets posted by the U.S. Twitter users, we use the geo-location disclosed in the users’ profiles to filter out the tweets from non-US users. Similar to Lyu et al. [2020], the locations with noise are excluded. 1.6 million geotagged tweets as well as the retweets posted from April 12, 2021 to May 7, 2021 are collected.

CDC COVID-19 Data

The daily state-level number of people with at least one dose, confirmed cases, and deaths per hundred are extracted from the CDC COVID Data Tracker (Centers for Disease Control and Prevention[2021]).

Census Data

From the latest American Community Survey 5-Year Data (2015-2019) (U.S. Census Bureau [2020]), we collect (1) the percentage of male persons; (2) the percentage of persons aged 65 years and over; (3) the percentage of White alone, not Hispanic or Latino; (4) the percentage of Black or African American alone; (5) the percentage of Asian alone; (6) the percentage of Hispanic or Latino; (7) the percentage of persons aged 25 years and over with a Bachelor’s degree or higher; (8) the percentage of persons in the labour force (16 years and over); and (9) per capita income in the past 12 months (in 2019 dollars).

1https://www.tweepy.org/ [Accessed June 9, 2021]
2The capitalization of non-hashtag keywords does not matter in the Tweepy query.
2020 National Popular Vote Data

The results of the 2020 national popular vote (Wasserman et al. 2020) are used to estimate the political affiliation of individual states. Since the sums of the shares of Biden and the shares of Trump are almost equal to 100%, we only select the shares of Biden. To keep the consistency among the variables, the state-level shares are chosen.

Methodology

Tweets Classification

Following the method of Bovet and Makse (2019), we intend to classify the tweets into (1) fake-news-related, (2) fact-related, and (3) others, by examining the URLs (if any) of the tweets. More specifically, if the URL’s domain name is judged to be related to the websites containing fake news, conspiracy theories, or extremely biased news, the tweets that are associated with (i.e., contain/retweet/quote) this URL are classified as fake-news-related. If the URL’s domain name is judged to be related to the websites that are traditional, fact-based, news outlets, the tweets that are associated with this URL are classified as fact-related. If the tweets are not associated with any URLs or the URLs’s domain names are not identified as fake-news-related or fact-related, the tweets are classified as others.

Websites Classification

The curated list of fake-news-related websites, composed of 1,125 unique domain names, was reported by Bovet and Makse (2019). They built the list by merging the major curated fake-news site lists provided by fact-checking groups like PolitiFact, FactCheck, OpenSources, and Snopes. The domain names that were assigned as fake, conspiracy, bias, and unreliable are included in our study.

The curated list of fact-related websites, composed of 77 unique domain names, was derived from the Columbia Journalism Review. They identified the most important traditional news outlets by manually inspecting the list of top 250 URLs’ domain names.

Extracting Domain Names

The tweets with no URLs are classified as others. For the rest, we compare the domain names of the URLs of the tweets with the aforementioned curated lists. Similarly to Bovet and Makse (2019), most URLs are shortened. We use the Python Requests package to open the URLs and extract the actual domain names from the complete URLs.

Preprocessing

The daily state-level number of people with at least one dose, confirmed cases, deaths per hundred are transformed using a two-step procedure. First, we calculate the relative change rates of these three variables. Next, we smooth the data using a simple moving average. According to the CDC vaccination data (Centers for Disease Control and Prevention 2021), there is a seasonal pattern inside the daily number of people with at least one dose. The number normally reaches the highest in the middle of the week (i.e., Thursdays), and approaches the lowest on weekends. Therefore, we apply a 7-day moving average to the vaccination data. To maintain the consistency, the number of confirmed cases and deaths are processed in the same way.

As for the Twitter data, since Twitter users can post tweets repeatedly, the series of (1) the percentage of unique Twitter users who post fake-news-related tweets, and (2) the percentage of unique Twitter users who post fact-related tweets are only processed with a 7-day moving average.

Study Period

This study focuses on understanding the influence of misinformation about COVID-19 vaccines on Twitter on the vaccine uptake. The CDC vaccination data may not reflect the intention to receive vaccination when the vaccines were not available for all the U.S. adults. We thus set the study period to be from April 19, 2021 to May 7, 2021. April 19 is selected as the start date because, according to the Reuters,[4] the U.S. President Joe Biden moved up the COVID-19 vaccine eligibility target for all American adults to April 19.

Fama-MacBeth Regression

In our study, we attempt to analyze five time series data, but most of them are non-stationary. For example, the time series of the vaccination data show a declining trend during our study period. Noticeably, the vaccination data, at this stage, has already been transformed into a relative change rate. To avoid the spurious regression problem, which might lead to a incorrectly estimated linear relationship between non-stationary time series variables (Kao 1999), we conduct the Fama-MacBeth regression (Fama and MacBeth 2021) with the Newey-West adjustment (lag=2) (Newey and West 1986), which has also been applied in several previous studies to address the time effect in areas such as finance (Loughran and Ritter 1996), public health and epidemiology (Wang et al. 2021). Apart from the time series data, we add control variables from the aforementioned data sources including the Census data and the 2020 National Popular Vote data.

Results

News Spreading on Twitter

There are 616 unique Twitter users who are associated with fake news, while 11,948 that are associated with fact-based news. Interestingly, 184 are associated with both fake news and fact-based news, which account for 29.9% and 1.5% of the fake-news-related users and fact-related users, respectively. This suggests that people who are associated with fake news are more likely to be associated with fact-based news, but not the other way around.

The state-level percentages of fake-news-related and fact-related Twitter users are presented in Figure 1[1]. The states without sufficient data (at least 300 unique Twitter users)

[1]https://www.cjr.org/fake-beta [Accessed June 9, 2021]
Figure 1: (a) Percentage of the Twitter users associated with tweets linked to fake news. (b) Percentage of the Twitter users associated with tweets linked to traditional news outlets.

Table 1 lists the top 10 most frequent tweets linked to fake and fact-based news websites. The top 10 most frequent fake-news-related tweets account for 19.9% of the number of the total fake-news-related tweets, while the top 10 of the fact-related tweets comprise of 28.1%, which indicates that the distribution of the fake news on Twitter is more even compared to the fact-based news. This is consistent with the pattern of the fake and fact-related tweets during the 2016 presidential election [Bovet and Makse 2019]. By reading the text alone, it is difficult to distinguish the fake news from the fact-based news. The structures of these two types of news are similar. For example, capitalizing all the letters of the first word is observed in both group. In addition, the text of both groups describes actions or quotes sentences from political figures and celebrities.

As aforementioned, there is a group of Twitter users who are involved with spreading both fake news and fact-based news. To better understand the difference of the fake-news-related and fact-related tweets, we further highlight in bold the tweets that are most frequently posted, retweeted or quoted by the users who are related to both fake news and fact-based news in Table 1. It is interesting that the news that are spread by this group of users is mostly negative about the COVID-19 vaccines. Moreover, when these users post tweets linked to fact-based news, they are most likely to show a negative attitude towards the vaccines. For example, they argue “Pure evil.” to a piece of news with the title “Children as young as 6 months old now in COVID-19 vaccine trials” written by ABC News.

Figure 2: Percent of the population receiving at least one dose.

Fake News, Fact-based News, and Vaccination Rate

We conduct the Fama-MacBeth regression with the Newey-West adjustment (lag=2) of the 7-day average relative change of the number of people receiving at least one dose per hundred, on the 7-day average percentages of unique fake-news-related and fact-related Twitter users, during the period when all U.S. adults are eligible for COVID-19 vaccines, while controlling other factors. Figure 2 shows the vaccination rates for different U.S. states as of May 7, 2021. Table 2 summarizes the results of the Fama-MacBeth regression, which suggest marginal effects of the fake news and fact-based news on the vaccination rate. Overall, the percentages of fake-news-related and fact-based new-related Twitter users are negatively associated with the relative change of vaccination rates: 1 percent increase in fake-news-related Twitter users is negatively associated with the relative change of the vaccination rate \( \beta = -0.13, SE = 0.07, p < .1 \); 1 percent increase in fact-related Twitter users is negatively associated with the relative change of the vaccination rate \( \beta = -0.04, SE = 0.02, p < .1 \). Even the percentage of fact-related Twitter users is almost 20 times the percentage of fake-news-related Twitter users, the coefficient of the fake-news-related user rate is greater.

Control Variables

Some of the control variables are significantly associated with the vaccination rate. Demographically, 1 percent increase in the fraction of male population is negatively as-

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5https://abcnews.go.com/US/children-young-months-now-covid-19-vaccine-trials/story?id=77353416 [Accessed June 9, 2021]
| Fake                                                                                                                                                                                                 | Fact-based                                                                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Americans Will Officially Need A Vaccine Passport For Travel To Europe In 2021                                                                                                                      | BREAKING: U.S. health officials say fully vaccinated Americans don’t need to wear masks outdoors anymore unless they are in a big crowd of strangers.                                                            |
| Cuomo Announces Separate Baseball Stadium Seating For Vaccinated And Unvaccinated Fans                                                                                                                 | JUST IN: All adults in US now eligible for COVID-19 vaccine                                                                                                                                                 |
| Joe Rogan Says Not To Get Vaccinated If You’re Young, Sparks Massive Backlash                                                                                                                           | Herpes infection possibly linked to COVID-19 vaccine, study says                                                                                                                                              |
| Vaccination Site Denying Appointments To White People In The Name Of ‘Equity’                                                                                                                          | These poll numbers prove it: People who refuse to wear masks or respect social distance are also refusing vaccination. They’re holding us back from resuming normal life. In fact, they’re counting on the rest of us to get vaccinated so they don’t have to. |
| ANALYSIS: After A Year Of Being Wrong, Experts Confused About ‘Vaccine Hesitancy’                                                                                                                    | WATCH: Fauci calls out GOP Sen. Johnson’s questioning of vaccine effort: "How can anyone say that 567,000 dead Americans is not an emergency?"                                                                 |
| Shh — The Media Doesn’t Seem To Want You To Know COVID-19 Cases Are Plummeting Nationally                                                                                                             | BREAKING: Vaccinated people can ditch the mask outdoors in many cases, CDC says—but should still wear one in crowds and indoor public spaces.                                                             |
| Has general population been enrolled in a vast and unimaginably dangerous phase-three clinical trial without legal informed consent? This is a criminal enterprise, the likes of which this world has never seen before... | U.S. health officials conclude that it was anxiety, and not a problem with the coronavirus vaccine, that caused apparent reactions in dozens of people this month. Basically, some people get so upset by injections that their anxiety spurs physical symptoms. |
| It’s Not Working: 86 Million Vaccinated, yet Daily Covid-19 Cases Are the Same as They Were in February                                                                                                  | Joe Rogan tells 21-year-olds not to get COVID vaccine on popular Spotify show                                                                                                                                 |
| Rand Paul has a brutal message for Joe Biden. via <user>                                                                                                                                              | ‘Ted Nugent tests positive for COVID-19 after refusing vaccine, falsely claiming “nobody knows what’s in it”                                                                                                   |
| ‘Follow The CCD Guidelines’ And ‘Visit Vaccines.Gum’: President Biden Gaffes His Way Through Press Conference                                                                                       | ‘On the Montana side of the border, vaccine recipients were often emotional, shedding tears, shouting words of gratitude through car windows as they drove away, and handing the nurses gifts such as chocolate and clothing.’                                                      |
associated with the relative change of the vaccination rate \((B = -0.11, SE = 0.03, p < .01)\). No statistically significant relationship is found between the percentage of persons aged 65 and over, which is within our expectation, since this demographic group is among the first batches who are eligible for the COVID-19 vaccines in the U.S. By the time of our study period, over 78% of the people aged 65 years and over have received at least one dose (Centers for Disease Control and Prevention [2021]). As for the race and ethnicity, the percentage of White alone, not Hispanic or Latino \((B = 0.00, SE = 0.00, p < .1)\) and the percentage of Asian alone \((B = 0.04, SE = 0.01, p < .001)\) are both positively associated with the vaccination rate. The patterns of the demographic variables are consistent with the ongoing vaccination trends (Centers for Disease Control and Prevention [2021]). With respect to the educational level, 1 percent increase in the percentage of persons aged 25 years and over with a Bachelor’s degree or higher is positively associated with the vaccination rate \((B = 0.11, SE = 0.03, p < .001)\). Socioeconomically, per capita income (in 2019 dollars) is negatively associated with the vaccination rate \((B = -2.68, SE = 4.90, p < .001)\). Furthermore, the daily COVID-19 confirmed cases is positively associated with the vaccination rate \((B = 0.12, SE = 0.06, p < .001)\). The shares of the 2020 National Popular Vote of Biden is positively associated with the vaccination rate \((B = 1.31, SE = 1.36, p < .001)\).

### Discussion and Conclusion

We identify the marginal negative correlations between the percentages of the U.S. Twitter users who are associated with fake news, fact-based news and the U.S. COVID-19 vaccination rates during the period when all U.S. adults are eligible for the COVID-19 vaccines. Montagni et al. [2021] argued that the acceptance of a COVID-19 vaccine is associated with ability to detect fake news and health literacy. However, by analyzing the content of the most frequent tweets linked to the fake news and fact-based news, we find that their structures are similar, which makes it difficult to distinguish one from another by reading the text alone. Furthermore, by examining the most frequent tweets that are posted by the users who are identified as spreading both fake news and fact-based news, we find that these overlapping users tend to post negative news about COVID-19 vaccines, and even the news is neutral, they are likely to show a negative attitude. It seems that it is the negativity inside the news instead of the authenticity of the news that is associated with the vaccination rates. Future work could investigate the causal relationship between the news and the vaccine uptake – whether the users who do not intend to take the vaccines tend to spread negative news or they read negative news and become resistant to the vaccines. Moreover, this work employs a method to identify fake news and fact-based news only using the URLs, which could potentially cause a sample bias. However, one of the advantages of this approach over other text-based machine learning or deep learning methods (Jin et al. [2016, 2017b]) is its high precision rate. In the future, we intend to combine these methods to detect fake news more reliably.

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