Unfolding determinants of COVID-19 vaccine acceptance in China:

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Table of Contents

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Abstract

Background: China is at the forefront of global efforts to develop COVID-19 vaccines and has five fast-tracked candidates in the final-stage, large scale human clinical trials tests. Layered on top of public engagement, making an informed and judicious choice is a catch-22 for the Chinese government in the context of COVID-19 vaccination promotion.

Objective: In this study, public opinions in China are analyzed via public dialogues on Chinese social media, based on which the views on COVID-19 vaccines and vaccination of Chinese netizens are investigated. We recommend strategies for promoting vaccination programs in the most populous country based on in-depth understanding of the challenges in risk communication and social mobilizations.

Methods: We proposed a novel emotional dynamics model SRS/I to analyze the opinion transmission paradigms on Chinese social media. Coupled with meta-analysis and natural language processing (NLP) techniques, the emotion polarity of individual opinion is examined in contexts.

Results: We collected more than 1.75 million Weibo messages about COVID-19 vaccines from January to October in 2020. According to the public opinion reproduction ratio (R_0), the dynamic propagation of those messages can be classified into three-stage: the Ferment period (R_0,1.1360), the Evolution period (R_0, 2.8278) and the Transmission period (R_0, 3.0729). Significantly, the topics on COVID-19 vaccine acceptance in China are emerging from the landscape of public opinion transmission, such as Price, side effects, and the like. From September to October, 18.3% people held the idea that the vaccine price is high and gets 38.1% “likes,” while 35.9% people regarded it as inexpensive with 25.0% “likes.”
The netizen’s emotional polarity on side effects is also the aspect of our research. We got 47.7% positive and 31.9% negative comments. We also captured that the inactivated vaccines aroused much more heated discussion than any other type of vaccine. It accounts for 53% of Discussions of all types’ vaccines, 42% of Forwards, 56% of Comments, and 49% of Likes.

Conclusions: Most Chinese hold that the vaccine is cheaper than previously thought, while some claim they could not afford it for their entire family. The Chinese are inclined to be positive to side effects over time and proud of China’s development regarding vaccines. Nevertheless, they have a collective misunderstanding about inactivated vaccines, insisting that inactivated vaccines are safer than other vaccines. Reflecting on those collective responses, the unfolding determinants of COVID-19 vaccine acceptance provide illuminating benchmarks for vaccine-promoting policy-makings.

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Unfolding determinants of COVID-19 vaccine acceptance in China

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ABSTRACT

Background: China is at the forefront of global efforts to develop COVID-19 vaccines and has five fast-tracked candidates in the final-stage, large scale human clinical trials tests. Layered on top of public engagement, making an informed and judicious choice is a dilemma for the Chinese government in the context of COVID-19 vaccination promotion.
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Conclusions: Most Chinese believe that the vaccine is cheaper than previously thought, while some claim they could not afford it for their entire family. The Chinese are inclined to be positive to side effects over time and proud of China's development regarding vaccines. Nevertheless, they have a collective misunderstanding about inactivated vaccines, insisting that inactivated vaccines are safer than other vaccines. Reflecting on those collective responses, the unfolding determinants of COVID-19 vaccine acceptance provide illuminating benchmarks for vaccine-promoting policy-makings.

KEYWORDS

COVID-19 vaccines; COVID-19 vaccination; affordability; efficacy; risk communication; evidence communication

Introduction

Vaccines have been proven to be an extremely effective means to deal with the epidemic in long-term human history [1]. However, over the past decades, the anti-vaccine or anti-vaccination movements sprung up exuberantly

in Europe and American [2, 3]. The anti-vaccine movements featured with vaccine hesitancy have emerged as significant public health problems, which topped the list of threats to global health [4] and fueled the contagious infections of measles in 2019 [5, 6]. What is worse, anti-vaccination misinformation spread more quickly than positive counterparts [7]. Immediately after declaring COVID-19 as a pandemic, numerous wild conspiracy theories sprouted through social media [8-10]. In Pakistan, two well-known political figures raised conspiracy theories against COVID-19 vaccines in the local community and further fed the trolls of vaccine hesitancy [11]. Neil et al. [12] proposed a heuristic map of COVID-19 vaccines' online contentions that reveals a multi-sided landscape of unprecedented intricacy about vaccines. The reasons for vaccine refusal are complex and different according to geographical and sociocultural contexts.

Many studies have shown that even vaccinated individuals may have substantial doubts and concerns regarding vaccination [13-15]. Many experts consider that vaccination programs are threatened by growing concerns among the population regarding vaccines' safety and efficacy [16-18]. According to previous estimates, less than 5-10% of individuals have strong anti-vaccination convictions [19]. However, a more significant proportion could be categorized as being vaccine hesitancy [20]. Vaccine hesitancy, defined as individual-level reluctance to receive vaccines, maybe fueled by a spectrum of held views regarding vaccination spanning from cautious acceptors to outright deniers [21-23]. Amin et al. [24] proposed that values-based messages appeal to core morality, influencing individuals' attitudes on topics like vaccination. They showed two correlational studies that harm and fairness foundations are not significantly associated with vaccine hesitancy, but purity and liberty foundations are. Besides, politics and public trust may affect public perceptions of vaccine risks. Larson [25] hold that there are the following aspects: Some risks of vaccines, such as side effect, provoke anxiety, reluctance, and rejection of vaccination; Vaccines are regulated, and sometimes mandated, by the government, and vaccination is resisted by those who feel their freedom is being imposed upon. And those who do not trust the government sometimes extend their distrust to vaccines produced by pharmaceutical companies, which will generate profits and arouse public concern about the motives of vaccine production. By examining the anti-vaccine situation in Texas, Martin [26] also concluded that the anti-vaccine community, at large, believes that vaccines are a tool of government control that makes big pharmaceutical companies rich and have side effects that can cause lasting damage. Amongst the barriers to universal vaccination, misinformation regarding the benefits, medicinal composition, and adverse effects of vaccination limits individuals' understanding and overall buy-in [27]. It can be seen that vaccine safety concerns continue to be an essential driver of decreasing vaccine uptake in most contexts [28-30]. These reports indicate that the vaccination opinion has a significant influence on the vaccine's development and marketing.

However, on the verge of effective COVID-19 vaccines hitting the market, collective response to vaccine candidates and vaccination in China remains unknown. As for the COVID-19, it has been shown to have high human-to-human transmissibility [32-34]. The ability to infect people through asymptomatic carriers can remain unnoticed and quickly disseminate itself, making the disease contain a confounding public health challenge [35-37]. Therefore, vaccine development studies have been carried out against COVID-19 by research teams in various companies and universities worldwide [38, 39]. Among them, Chinese research on COVID-19 vaccines is a special case, which covers almost all types of vaccines. However, The COVID-19 vaccine development has created a hot discussion for the COVID-19 vaccine [40]. Different countries have different attitudes toward vaccine developments. For example, the Japanese government considers the free COVID-19 vaccination for all residents when it becomes available [41]. However, some carried placards with anti-vaccine slogans at rallies in California to protest against the lockdown. Subsequently, anti-vaccine movements have also taken place in London and other cities [42,43]. In China, although more than 90,000 families have been affected by the epidemic [31], there is no such movement happened in the most populous country, yet it does not mean that there is no contention on COVID-19 vaccines and vaccination. Hence, it is of great importance to uncover the collective propensities in social dialogues and facilitate authorities making reasonable and informed decisions.

Considerable variation by country would determine the COVID-19 vaccine acceptance [44].To this end, this country-specific study aims to articulate the paradigm of public engagement in COVID-19 vaccination for scrutinizing the practical strategies of preparedness to mitigate the pandemic in China. This study investigates the dissemination of hot topics related to the COVID-19 vaccines on Weibo, obtains public opinions and propensities on the COVID-19 vaccines, such as vaccine price, side effects, etc.

Study Objectives

We aim to examine what Chinese netizens are concerned about COVID-19 vaccines and vaccination by profiling the pertinent topics on Sina microblogs (Weibo). We take random samples of more than 10 million Weibo messages from January to October 2020 to address the following research issues: the affordability of COVID-19 vaccine candidates; the efficacy of COVID-19 vaccine candidates; and propensities to COVID-19 vaccination. We

also tend to unveil the underlying motives behind the paradigms of these public appeals and explore the potential strategies of preparedness to health and risk communication.

Methods

Data Collection

Weibo is thought of as a natural experiment that profiles social responses to a Chinese public health major preparedness. As the leading Chinese social media characterized by heterogeneous communities, it is a crucial public opinion battlefield in China. As of December 2018, Weibo had 462 million active users per month, which had increased by more than 70 million in the continuous three years, and had 200 million active users with 130 million words posted per day [45]. Chinese netizens regard this platform as dominant a outlet for expressing their demands and appeals [46]. More and more messages were posted, read, forwarded, and commented on. Clusters of messages can be found on different topics marked by "#" due to the similarity of their contents. The benefit of this mechanism, messages, and topics is spread widely with large-scale participation. The mechanism is also a routine process to accumulate comprehensive reflections of opinion polls.

In this study, benefiting from more than 500 million active users per month in 2020, we retrieved more than 1.75 million Weibo messages with approximately 21.17 billion links posted worldwide from January to October in 2020. Besides, we classified the reliability of the messages being circulated. The messages were in 108 languages from all around the world, but because of our data filtering and enrichment procedures, the largest fraction of analyzed messages point to Chinese-language sources (Simplified Chinese and Traditional Chinese). Additionally, for each message, verification is performed by Sina Corporation to clearly identify accounts of public interest and certify that they are authentic, according to the real-name verification policy on the uses of microblogs in China. As a bonus of these, the findings reported in this study mostly capture the social behaviors of the Chinese-speaking portion of Weibo users, including domestic Chinese and diaspora.

We utilize natural language processing (NLP) to screen out all the Weibo topics on the COVID-19 vaccines from the end of January to the beginning of October and obtained 989 topics. Of those, the typical, pertinent, and clustered topics are highlighted in **Table 1**.

Table 1. Typical topics related to the COVID-19 vaccine, containing the metadata about topic name, reading quantity, and date.

Recommended topic name	Reading (million)	Date
#COVID-19 vaccine could be available in early 2021#	820	Feb 9
#Wei Chen's Team conducts the Phase I clinical trial of COVID-19 vaccine#	243.8	Mar 20
#When will the COVID-19 vaccine be available#	50.9	Apr 14
# China's COVID-19 vaccine has entered Phase II clinical trial#	33	Apr 14
#The first participant of the COVID-19 vaccine has not yet collected adverse reactions#	21	Apr 14
#The world's first COVID-19 inactivated vaccine#	41.2	Apr 19
#What is the COVID-19 inactivated vaccine#	25.2	Apr 21
#Chinese first COVID-19 inactivated vaccine entered Phase II clinical trial#	4566.4	Apr 24
#Phase I clinical trial of Chinese first COVID-19 vaccine has good results#	934.5	May 22
#The safety and effectiveness of the COVID-19 inactivated vaccine have been verified#	76.9	May 29
#More than 2000 people received the COVID-19 inactivated vaccine injection#	479.6	May 30
#COVID-19 inactivated vaccine is expected to be available at the end of this year or early next year#	162.1	May 30
#China developed another kind of COVID-19 inactivated vaccine#	2000	Jun 9
# World's first COVID-19 inactivated vaccine participant produces antibodies#	39.4	Jun 17
#Chinese COVID-19 vaccine will be launched as early as 2021#	37.9	Jun 18
#CNBG's COVID-19 inactivated vaccine is not affected by virus mutation#	1276.2	Jun 19
#Chinese three COVID-19 vaccines complete Phase II clinical trials#	18000	Jun 20
#Domestic COVID-19 inactivated vaccine launches international clinical phase Ⅲ trial#	84.2	Jun 23
#COVID-19 inactivated vaccine production workshop is completed in Wuhan#	7388.4	Jul 2
#WHO requires the protection period of the COVID-19 vaccine to be at least six months#	56.8	Jul 3
#Chinese COVID-19 vaccine Phase 2 clinical trial achieves good results#	131	Jul 21
#COVID-19 vaccine may be available at the end of the year#	345.4	Jul 22
#World first officially releases Phase II clinical data of COVID-19#	238.3	Jul 23
#The price of the COVID-19 vaccine will not exceed $40#	888.9	Jul 29
#Russian COVID-19 vaccine will be free of charge#	20000	Aug 1
#The first COVID-19 inactivated vaccine workshop passed safety inspection#	44.9	Aug 5
#Beijing COVID-19 inactivated vaccine production workshop can be put into production at any time#	45.5	Aug 5
#Half of the COVID-19 vaccines in Phase III clinical trials come from China#	150.6	Aug 7
#Gates required the COVID-19 vaccine to be priced below $3#	963.7	Aug 8
#Research Institute refutes rumors of COVID-19 vaccine 498 yuan an injection#	127.4	Aug 13
#COVID-19 vaccine not yet be available#	3	Aug 13
#COVID-19 inactivated vaccine two injections less than one thousand yuan#	3081.6	Aug 18

#Domestic COVID-19 inactivated vaccine is expected to be available at the end of December#	131.6	Aug 18
#Russian second COVID-19 vaccine starts Phase 2 clinical trial#	70.1	Aug 18
#COVID-19 vaccine two injections 1000 yuan is too expensive#	24.2	Aug 19
#The price of COVID-19 vaccine can only be based on cost#	17000	Aug 23
#How to price the COVID-19 vaccine#	254.2	Aug 23
#CNBG declared COVID-19 vaccine is likely to be available at the end of this year#	354.6	Aug 23
#National Health Commission Claimed that the price of COVID-19 vaccine was lower than two injections of 1,000 yuan#	65.9	Aug 23
#Domestic COVID-19 inactivated vaccine first appears#	19000	Sept 5
#Domestic COVID-19 inactivated vaccine appears in CIFTIS#	5766.4	Sept 6
#The COVID-19 vaccine will be priced based on factors such as consumers' ability to pay#	134.5	Sept 7
#Domestic COVID-19 inactivated vaccine inoculates hundreds of thousands of people with zero infection#	2102.4	Sept 11
#Oxford vaccine volunteers have side effects#	769.1	Sept 9
#The COVID-19 vaccine produced by Pfizer in America has side effect#	17000	Sept 16
#The COVID-19 inactivated vaccine is expected to be available at the end of the year#	4319.2	Sept 8
#The COVID-19 vaccine price in China will be within the scope of public acceptance#	11000	Sept 2
#The COVID-19 inactivated vaccine is only one kilometer away from success#	23000	Sept 2
#Two injections 600 yuan for domestic COVID-19 vaccine #	7737	Sept 3
#The price of domestic COVID-19 vaccine is released#	4413.4	Sept 2
#Four COVID-19 vaccines in China enter Phase III clinical trials#	428.6	Sept 2
#China formally joins COVAX#	23000	Oct 9

Behavioral dynamics model: SRS/I

On social media, the propagation and inline influence of various topics are involved. To track the derivative development of topics related to the COVID-19 vaccines in China, we propose a dynamics model SRS/I based on a complex network to investigate the landscape of public opinion transmission (**Figure 1**) [47]. The SRS/I model promise to profile the collective propensities of different populations to different topics at different times on social media.

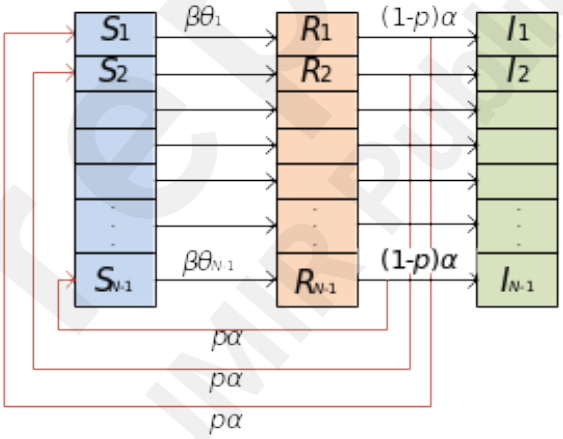


Figure 1. Inspired by infectious disease models, a network model diagram of information dissemination is proposed to simulate the transmission of information among the susceptible state (*S*), the reading state (*R*), and the immunized state (*I*).

We consider a reading population on topics about the vaccine of Weibo users, stratified in terms of three distinct stages: the susceptible state (S), in which the users unaware of but susceptible to the information of the event; the reading state (R), in which the users have read information actively to influence other users; and the immunized state (I), in which the users have read the information, and can trick a new round of reading activities of the same topic. We obtain the following SRS/I reading dynamics model of topics about the vaccines:

$$\frac{d}{dt}S(t) = -\beta\langle k\rangle S(t)R(t) + p\alpha R(t) \quad (1)$$

$$\frac{d}{dt}R(t) = \beta\langle k\rangle S(t)R(t) - \alpha R(t) \quad (2)$$

$$\frac{d}{dt}I(t) = (1-p)\alpha R(t) \quad (3)$$

Where β means the average exposure rate of a susceptible user who can read topics about the vaccine. Since an active reading user will contact an average number of βN users per unit time and the probability of a contacted user is a susceptible user is $S(t)/N$, the number of new reading users is $\beta\langle k\rangle N(S(t)/N)R(t)=\beta\langle k\rangle S(t)R(t)$. Users who can become inactive to the same topic with an average inactive rate α, with $1/\alpha$ being the average duration where an R-user remains active in reading. The average number of inactive users will be $\alpha R(t)$ per unit time, among which $p\alpha R(t)$ will re-enter to the susceptible state where exposure to another Weibo within the same topic can initiate a new round of readings, and $(1-p)\alpha R(t)$ will go to the immunized state directly, in which p reflect the "re-entering" probability for a reading user who can trick a new round of reading activities of the same topic. θ is a parameter related to the topics' dissemination network of vaccine, and in this paper, we only consider the average degree $\langle k\rangle$.

We extend the basic reproduction number R_0 [48] of epidemiology in the field of information transmission. In our SRS/I dynamics model, we define the public opinion reproduction ratio R_0 to measure the potential impacts of topics in the initial propagation stage of topics, which is given by $R'(0)=(\beta\langle k\rangle S_0-\alpha)R(0)$, and the outbreak will never take off since $R'(0)=(\beta\langle k\rangle S_0-\alpha)R(0)<0$ due to the decrease of S. Then we deduce

$$R_0 := \frac{\beta\langle k\rangle S_0}{\alpha} \tag{4}$$

To further explore the Chinese opinion about the COVID-19 vaccines, we collect the metadata, which includes the names and reading quantity of related topics from the end of January to the beginning of October, through an API provided by Weibo. **Table 1** shows several specific topics on COVID-19 vaccines with their posted date and reading quantity. The date can facilitate us identifying the continuity of topics over time, while the reading quantity could reflect the collective attentions of the population.

The landscape of public opinion transmission

After numerical fitting and calculation, according to the basic reproduction number R_0, we found that a paradigm shift emerged in July. The R_0 value becomes large this month, which means Chinese netizens have become more interested in vaccines. Therefore, we divided the transmission process of vaccine-related topics into three stages: Ferment period (Stage 1, the end of January to June), Evolution period (Stage 2, July), and Transmission period (Stage 3, August to the beginning of October)(**Figure 2**). Their public opinion reproduction ratio is specifically expressed as R_{01}, R_{02}, and R_{03}, where R_{01} = 1.1360, R_{02} = 2.8278, R_{03} = 3.0729. Obviously, R_{03} is bigger than R_{01} and R_{02}. This is consistent with the fact that the topics in Stage 3 have been disseminated more widely than those in Stages 1 and 2. In Stage 3, two sensitive topics came to our attention: vaccines' price and vaccines' side effects. Topics about vaccines' Side effects (labels 44 and 45 in the **Multimedia Appendix 1**) reached more than 17000 million reading while topics about vaccine pricing (labels 24 and 25 in the **Multimedia Appendix 1**) have emerged in an endless stream and has been widely read. So, they arouse the continuous attention of Chinese netizens.

As shown in **Figure 2**, we obtained the metadata of the 989 penitent topics on Weibo. We consider the duration and content of topics that the Chinese are interest in. Topics were divided into seven categories based on contents. We found topics connected with the same specific event are casual as time goes by. Namely, one topic, whether it has a strong positive or negative sentiment or just is a general announcement, may affect the sensitivity of Chinese netizens to the COVID-19 vaccine, thereby can involve the population to facilitate the creation of new types of topics or a derivation of old ones.

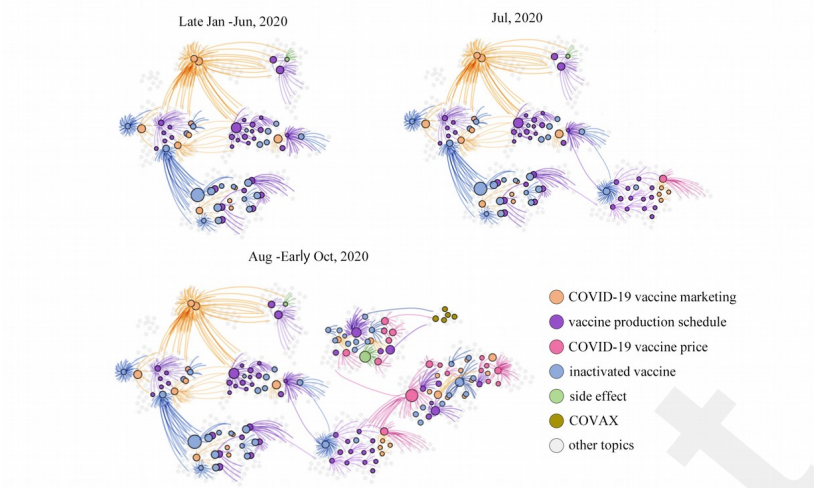


Figure 2. The landscape of public opinion transmission on vaccines-related topics. The seven different colored dots represent the seven main topics. The lines between them represent the mutual influence between them, and the density of the lines represents the degree of influence.

Price acceptance

We collected all the messages and their likes on all price-related topics mentioned above. We set keywords and use the following formula to calculate the price tendency. After tokenization and word extraction process, we obtain M words, which are synonyms for "Expensive," expressed as $(E¿¿1, E¿¿2, \ldots, E_M)¿¿$. By querying in the dictionary (**Multimedia Appendix 2**), we denote the weight of the i_{th} word as a_i. Hence, the score of "Expensive" is computed as:

$$S_E = \sum_i^M a_i E_i , \tag{4}$$

In the same vein, we obtain N words, synonyms for "Cheap," expressed as $(C¿¿1, C¿¿2, \ldots, C_N)¿¿$. After querying in the dictionary, the weight of the i_{th} word a_i is obtained. The score of "Cheap" is expressed as:

$$S_C = \sum_i^N a_i C_i , \tag{5}$$

The final expression of the price tendency score can be obtained as:

$$S = S_E - S_C = \sum_i^M a_i E_i - \sum_i^N a_i C_i , \tag{6}$$

when $S>0$, it means that the population regards the price is high. On the contrary, if $S<0$, it means that the collective attitudes towards price are acceptable.

Sentiment polarity of side effect

We analyze the sentiment of 925 messages on the side-effect topics based on the general Chinese lexicon HowNet [49]. For a text sequence $x = \{w_1, \ldots\ldots, w_k, \ldots\ldots, w_K\}$, where w_k indicates that the k-th word in sequence x, K is the total word number for the sequence x. Then we obtain the corresponding sentimental values $Sen_x = \{S_U(w_1), \ldots\ldots, S_U(w_k), \ldots\ldots, S_U(w_K)\}$ of each word in x by sentiment lexicon rescores to synthesize the final sentence sentiment value S_x:

$$S_x = \sum_{k=1}^K S_U(w_k) , \tag{7}$$

where $S_U(w_k)$ is the sentiment value for the *k*-th word in sequence x calculated by our used sentiment lexicon, S_x is the sentiment value of the sequence x. We turn S_x it into polarity T_x as following for the convenience of the judgment of the performance of our sentiment classification task.

$$T_x = \begin{cases} 1, S_x > 0 \\ 0, S_x = 0 \\ -1, S_x < 0 \end{cases} , \tag{8}$$

where we count the sum of T_x of each case, denoted by NP, NN, and ZN, respectively. We further calculate the proportion of each sentiment tendency in all corpora:

$$pos(\%)=\frac{PN}{N}\times 100\%, \quad (9)$$

$$\neg(\%)=\frac{NN}{N}\times 100\%, \quad (10)$$

where N is the total number of corpora, $pos(\%)$, $\neg(\%)$ are represented as positive and negative sentiment proportion, respectively.

In the sampling inspection, due to the Chinese language's diversity, we validated the results of the sentiment lexicon-based method. We strictly followed the requirements of the double-blind experiment and invited three groups (A, B, and C) who had been reading the ability to classify these Weibos by emotion. When the emotion judged by group A and group B was consistent, we took it as the correct result. When the judgment between group A and B was inconsistent, group C made the final judgment. We mark the positive Weibos as 1, and the negative ones as -1, use the Formulas (9) and (10) to calculate manual labeling.

Results

Weibo's attitude influence map

In the case of affordability and efficacy, we chose two topics (#The COVID-19 vaccine price can only be based on cost#, #The COVID-19 vaccine produced by Pfizer in America has side effects#), where 169 Weibos and 220 Weibos have involved in, respectively. We utilized the SRS/I model to draw the Weibos' attitude influence map (Figure 3). The different colors on behalf of different attitudes. A topic is composed of individual Weibos, which have a content connection and time sequence relationship. In the initiation, the first Weibo had the ability to promote subsequent publishing and dissemination. In Figure 3, we use points to represent Weibos, which appear clockwise in chronological order. In terms of price (Figure 3(a)), most people thought the pricing of vaccines was inexpensive. Nevertheless, it is worth noting that there are still many people who feel the pricing of the vaccine was expensive post Weibos at various time periods. In terms of side effects (Figure 3(b)), initially, positive Weibos dominated, and over time, positive and negative views alternated in the majority, and the two views clashed during this time. On aggregate, positive dominates.

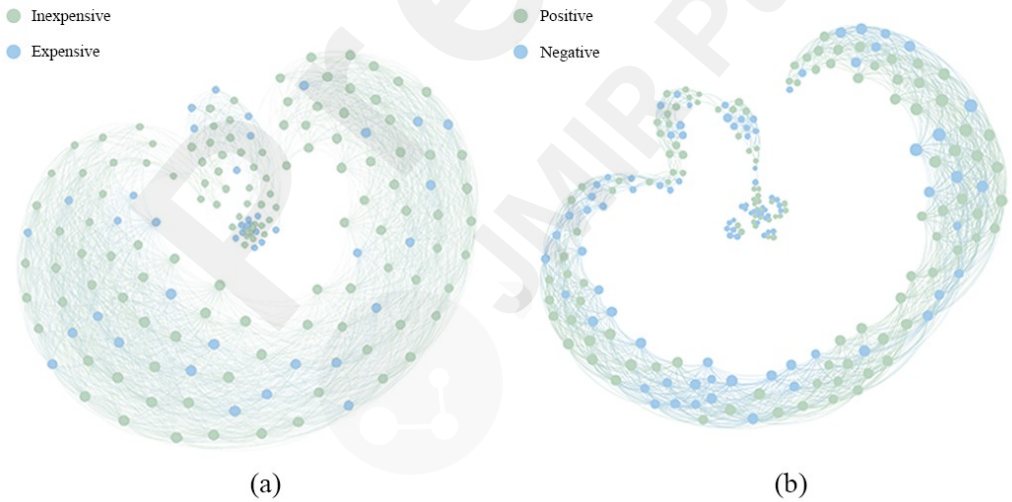


Figure 3. Weibo attitude contagion map: (a) Price; (b) Side effect. Points represent Weibos that appear in the figure in clockwise order, ending with the point at the center of the figure.

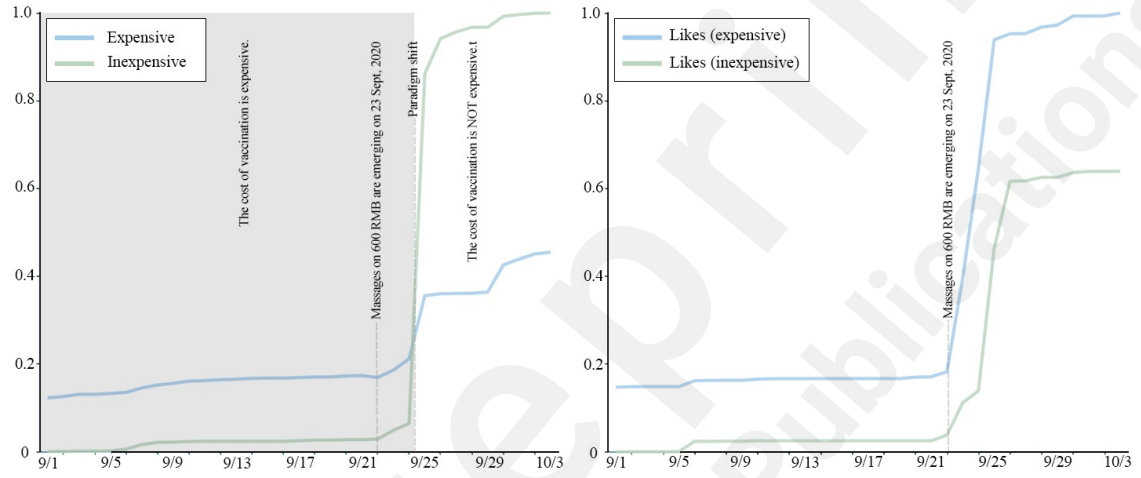
Affordability: The price of vaccines

We selected the metadata during the period when the paradigm of price tendency dramatically changed and obtained 4,925 related messages on Weibo. The final result is normalized (**Figure 4**). It can be seen in **Figure 4(a),** the collective attitudes towards COVID-19 vaccines' prices suddenly increased after September 23, from expensive to inexpensive. However, the population's "likes" had the opposite tendency, as shown in **Figure 4(b)**.

On Weibo, the topic of COVID-19 vaccine price has been emerged in July of 2020 and has attracted hundreds of millions of "onlookers" in China. However, the number of come-straight-to-the-point utterances on the price is not very large.

In August, Chinese governments had claimed that the Chinese vaccine price would not exceed 1,000 RMB. Therefore, the expected price is about 1,000 RMB, and most people think it is too expensive. Due to the one-child policy, young people may need to pay for their extended family. Although they believe that the cost of production is high, the cost of vaccination is not a small expenditure for ordinary families. After the Chinese COVID-19 vaccine fee was announced on September 23, 600 RMB (about US$ 90) for two shots, the number of relevant messages began to increase significantly(labels 49 in the **Multimedia Appendix 1**). As shown in **Figure 4(a)**, it is worth noting that the public had their own speculations about the prices of Chinese vaccines before this announcement. The public's attitudes have reversed after this tipping point, and most people think that the official price is acceptable. Most people prefer to click on "like" or post pithy Weibos to endorse those previous rational views on Weibo rather than posting similar messages themselves. As shown in **Figure 4(b)**, the collective emotional polarity did not reverse with the increase of such likes.

Certainly, the official price is still too expensive for some netizens. Comparatively speaking, citizens in developed countries have their own universal health insurance, or some countries promise to bear the costs of vaccinations. As a case in point, the Japanese government promises to pay the bill of vaccinations for citizens, as well as Russia ((labels 25 and 52 in the **Multimedia Appendix 1**). Therefore, some Chinese netizens naturally hope that China will follow suit. The patterns in **Figure 3(a)** also confirm the above findings.



(a) (b)

Figure 4. The paradigm shift of price tendency.

Efficacy: side effects of vaccines

We plot the lexicon-based sentiment classification results, and the manual labeled sentiment classification method in **Figure 5**. Generally speaking, the Chinese are optimistic about vaccines. Interestingly, Chinese netizens seem to be accustomed to expressing their positive opinions in diverse ways. These diverse utterances may undermine the accuracy rate of lexicon-based sentiment analysis, especially for the negative sentiment (**Figure 5**). The potential uncertainties may cause the miscalculation of the accuracy rate of emotion-cause pair extraction (ECPE) and identification of ironic contexts. For example, comparing **Figure 5(a)** with **Figure 5(b)**, Chinese netizens tend to express understanding for vaccine side effects in an ironic way. For instance, one Weibo posted, "I think most people cannot even understand the title," while another wrote, "if you have a little common sense in pharmacology… Is it weird to have an adverse event (AE)? How can it be on the hot search?" These Weibos' editors think that it is common sense that drugs have side effects. They have a positive attitude towards the side effects but scoff at those who have opposing opinions. However, these Weibos are judged neutral by the machine. There are also some Weibos judged to be negative, but their attitude towards side effects is positive. For example, a Weibo's content is, "Even taking vitamins will increase the liver's metabolic burden. All drugs are somewhat toxic. If a drug has no side effects, it must be fake." They know the potential danger of side effects but think it is within the acceptable range. Thus, their attitude towards vaccines' side effects is positive. Due to the phenomenon of "ironic," the results of the lexicon-based sentiment classification (Figure 5(a)) are inaccurate. Therefore, we only use the results obtained by manual labeling to determine Chinese netizens' attitudes towards side effects.

Figure 5(b) shows four significant patterns in June, August, and September. The trigger events were #Chinese inactivated vaccine's Phase I/II trial was complete, and the participants had no adverse reactions# (June 16), #The chairman of Sinopharm said he vaccination and no adverse reactions# (Aug 18), #Oxford vaccine volunteers experienced adverse reactions# (Sept 9), and #The COVID-19 vaccine produced by Pfizer in America has a side

effect# (Sept 16), respectively. The topics were more active in September. From the perspective of emotional polarity, the messages' polarity about the side effects of COVID-19 vaccines can directly and positively affect people's emotional polarity. Over time, positive information and negative information became dominant alternately. In the end, the Chinese views on side effects tend to be positive. The possible reason for this finding is that the positive emotions of prevailed messages on side effects result in herd behavior of the followers [50]. After such information cascades, the population gradually accepted the existence of side effects and then they reached a consensus (**Figure 5(b)**). In the same vein, **Figure 3(b)** shows similar patterns.

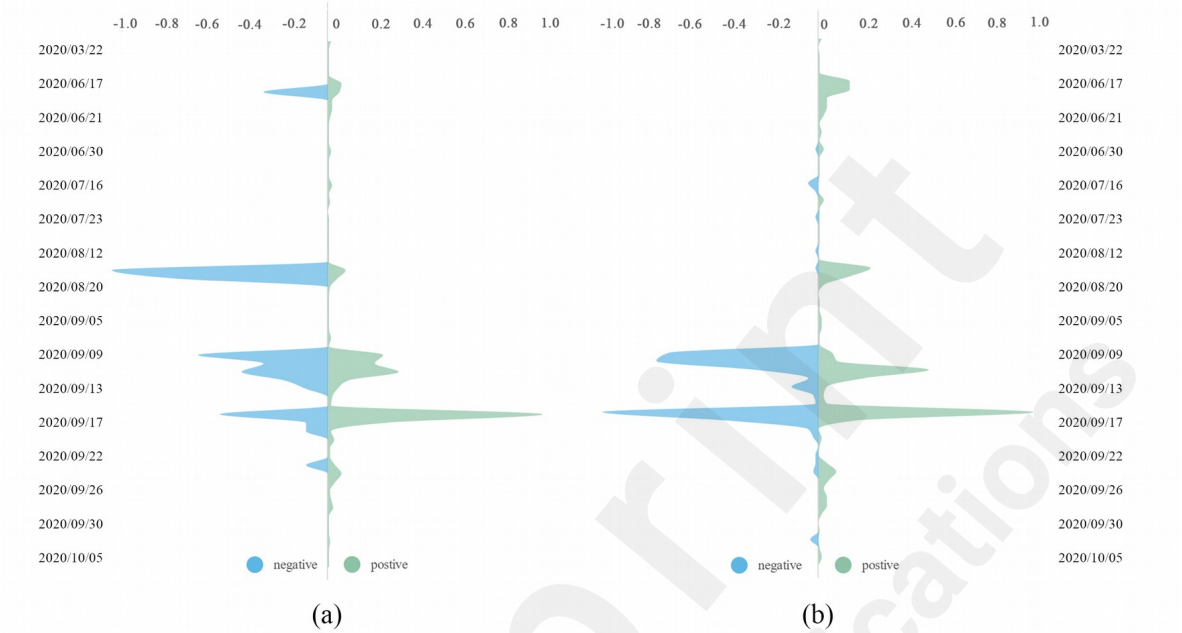


Figure 5. The collective attitudes towards side effects: (a) the results of the lexicon-based method, (b) the final results coupled with human labeling.

On the contrary, as *Nature News* reported, in high-income countries such as Europe, citizens' concern is no longer on the price but on safety [50]. Many people believe that vaccines will increase the immune system's burden, assuming that it exposes themselves to danger. Besides, a variety of more exaggerated rumors spread on major social media. According to Google Books Ngram Corpus (GBNC) (**Figure 6**), the cooccurrence of anti-vaccine and anti-vaccination movements has shown a clear upward trend in the past decades (The fitted slope of the anti-vaccination movement is 0.0844 and the anti-vaccine movement is 0.0789, respectively)[51]. The historical events that may have impacted the anti-vaccine and anti-vaccination movement in different eras were marked in the figure. It also shows that the concern for the safety of early vaccines has resulted in widespread protests. With the development of medical technology, vaccines have gradually become safer, and protests have decreased. Part of the reason for burgeoning movements in recent decades is due to ideological reasons [52]. However, as an exception, China has not experienced such scenarios. In view of this, in China, it is particularly important to timely collect public opinions via social media and improves policy-makings in due course.

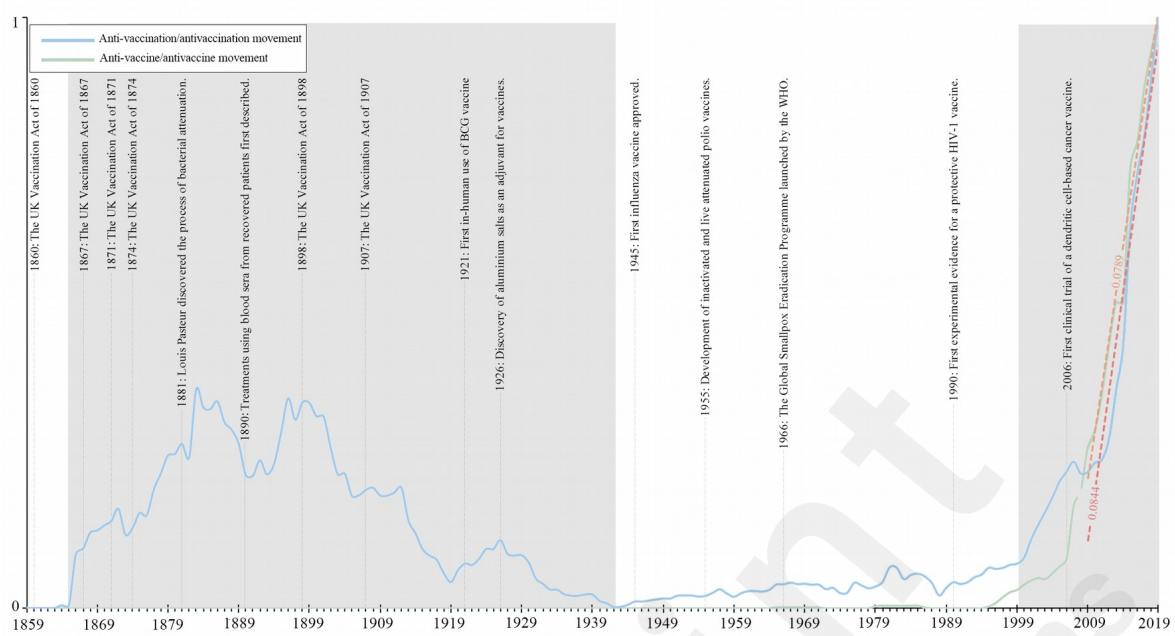


Figure 6. Google Books Ngram Corpus (GBNC) facsimiles word frequencies of “anti-vaccination/antivaccination movement” and “anti-vaccine/antivaccine movement” in English corpus from 1859 to 2019.

Hesitancy: type of vaccines

Vaccine hesitancy about COVID-19 vaccines is linked to populations who are reluctant or refuse to be vaccinated despite the availability of vaccination services [53]. The beliefs of vaccine hesitancy are dynamic, complex, and context-specific, varying across time, place, and vaccines, as well as complacency, convenience, and confidence. China is forging ahead in the race to develop COVID-19 vaccine candidates, which covered five potential development routines: inactivated vaccines, adenovirus vector vaccines, the vaccines using attenuated influenza viruses as vectors, recombinant protein vaccines, and nucleic acid vaccines (including RNA vaccines and DNA vaccines) [54]. China's National Medical Products Administration projected China’s production capacity of COVID-19 vaccines would reach 610 million doses annually by the end of 2020. Of these, the licensed vaccines for limited rollout would be inactivated vaccines [55].

Figure 7 shows the proportion of these five vaccines mentioned by Chinese netizens. We have selected four dimensions (Discussion, Forward, Comments, and Likes) to show the degree of attention of different vaccines. Obviously, the share of inactivated vaccines is almost more than the sum of the other four vaccines in terms of Discussion, Forward, Comments, and Likes.

Compared with other vaccines, inactivated vaccines are more acceptable to the public in China. The reason may be that the word “inactivated” in Chinese means “being killed” or “dead.” It gives people a sense of more secure than other genres. For the same reason, the vaccines using attenuated influenza viruses as vectors, which means “alive influenza virus” in Chinese, has been rarely mentioned by netizens. It accounts for less than 10% (**Figure 7**).

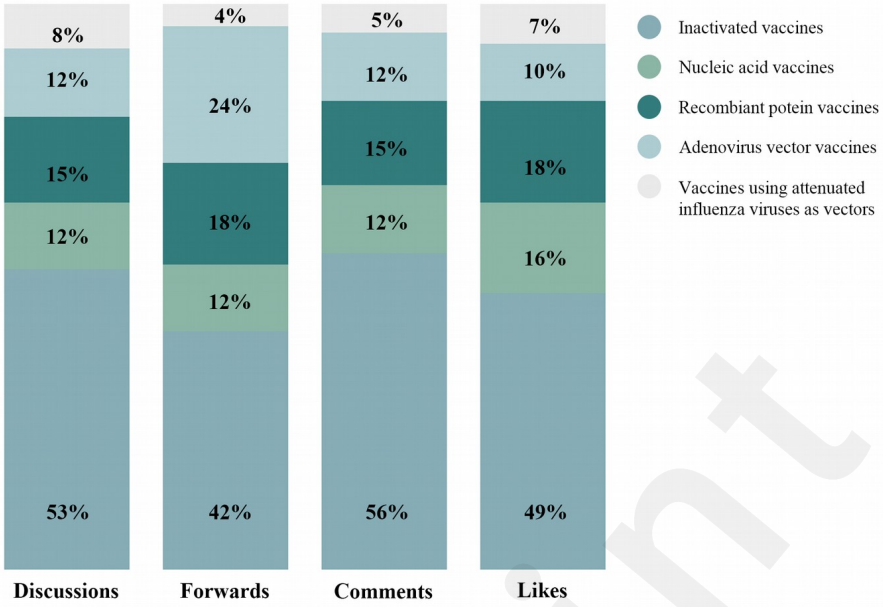


Figure 7. The distribution of netizens' attention to five different types of China-made vaccines.

Discussion

Principal Findings

Using rich random-sampling metadata of Chinese social media Weibo (more than 1.75 million messages with approximately 21.17 billion links), we conducted a country-specific study of real-time public awareness and behavioral responses to COVID-19 vaccines and vaccination from January to October in 2020. By studying the collective transmission behavior of Chinese netizens (domestic Chinese and diaspora), this research reveals the paradigm alteration of public demand and the reasons for its formation in the context of the promotion of COVID-19 vaccination.

Beyond affordability. Our new findings strongly suggest that the Chinese are divided in their favor prices of vaccination with different expectations. On the official price, supporters accepted the current price, whereas opponents claimed that it is unaffordable for their extended family. Arguably, the majority of people think that the price is lower than previously thought. If the Chinese government promise to pay for all-people vaccination, taking 600 RMB per person as an example, the most populous country would bear a financial burden of at least 840 billion RMB. Therefore, whether to introduce a follow-suit policy of free COVID-19 vaccination is an extremely difficult decision for the Chinese government to make. If the government simply and directly included COVID-19 vaccines in medical insurance, it would impose a financial burden on the hospital and eventually pass on the financial gap to patients [56]. If commercial insurance is subsidized, another problem will arise: Chinese families tend to insure low COVID-19 risk children rather than high-risk elderly people [57, 58].

Concerns raised over efficacy. Our study is characterized by a striking feature that people's concern about side effects tends to be positive over time. The news of fast-tracked China-made vaccine candidates is encouraging and helpful, but scientists urge caution [59]. Admittedly, the volunteers who received either the trial vaccine or placebo are low-risk, healthy adults rather than those high-risk populations (e.g., obese patients [60, 61], syndrome patients [62]. When it is extended to more general participants, many scientists hold that there is uncertainty about the vaccine candidates' true efficacy [63]. More observations are needed to test the effectiveness of the vaccine [64, 65]. On the contrary, the results of prevailed messages pinpoint that most Chinese could accept the marginal risk – side effects – with much confidence about the forthcoming vaccines.

Cognitive dissonance debunked. Last but not least, the literal meaning of the Chinese name for inactivated vaccines may provide a false sense of security. According to our survey, most Chinese reached a consensus on the safety of inactivated vaccines due to cognitive dissonance. By contrast, people's expectations for inactivated vaccines are higher than other types of vaccines. There is no scientific evidence support that inactivated vaccines are much safer than the other genres. What's more, even when the vaccine is proven to be safe and effective, acceptance of the vaccine varies by the group [66]. And WHO has listed vaccine hesitation as one of the top 10 threats to global health [67, 68]. It is usually caused by the association of moral values in the family [24, 69], but it is unnecessary [70]. Nevertheless, the biggest problem in China is cognitive dissonance. Being echoed by daily communications,

this finding indicates that this false cognitive predisposition would reinforce the tendency to vaccinate inactivated vaccines and discourage the vaccination of other types. Much worse, while other vaccines lose their competitive advantages, people may not choose the most suitable one or even lose their right to choose. As rare events often attack the safety of vaccines [71], dissonance can lead to collective misbehavior.

Limitations

On the one hand, in this study, we retrieved more than 1.75 million Weibo messages in about 108 languages, but only messages in Simplified Chinese and Traditional Chinese have been further investigated. Those messages may come from domestic Chinese, diaspora, or even foreign netizens living in China. Therefore, the findings reported in this study reflect the COVID-19 vaccine acceptance of the Chinese-speaking population. In fact, each account of netizens is authentic according to the real-name verification policy of China. And the authenticity of the message can be guaranteed, and they almost always come from real people rather than bots. With the objectives in mind, this limitation could not undermine the significance of the new findings.

On the other hand, the landscape of public opinion transmission is still ever-growing up, especially on Price, side effects, and the like. As the three major topics are still in the brewing stage, a large number of messages and interactions show up after this study. However, the paradigm shifts of all the pertinent topics discussed here have been observed. Therefore, this limitation should not undermine the significance of the study either.

In addition, according to the 46th “Statistical Report on Internet Development in China” released by China Internet Network Information Center (CNNIC) on September 29th, 2020, only 10.3% of Chinese netizens are over 60 years old. Therefore, to overcome the undersampling of the elderly population in this survey, the determinants of COVID-19 vaccine acceptance among older adults need to be investigated further [44].

Conclusions

At this critical moment in China, articulating dynamic social paradigms of public engagement in the forthcoming COVID-19 vaccination is paramount for examining the practical strategies of social mobilization, wherein one sheds light on the other’s significance. With an emphasis on the lens of the leading social media Weibo, we scrutinize collective responses on COVID-19 vaccines and pertinent discourses in sociocultural paradigms to uncover the collective propensities and the consequences.

As an integral component of preparedness, the contextualized results reported in this study promise to provide illuminating benchmarks to bridge the gaps of health and risk communications. In China, the landscape of public opinion transmission on Chinese social media is unique in the world, featured by the real-name verification policy. Therefore, the online collective propensities on the COVID-19 vaccines and vaccination could resonantly echo by daily responses in the real world, including those from domestic Chinese and diaspora. Without explicit anti-vaccine or anti-vaccination movements, but the implicit channel of online public appeals is more vital than ever for improving duly policy-makings in the round, lest these implicit appeals are neglected at our peril.

Our identified paradigms of the determinants of COVID-19 vaccine acceptance (e.g., public appeals on affordability, efficacy, and preferences) could reframe a heuristic framework for extensive discussions, especially on vaccine-promoting policy-makings in China. Reflecting on the unfolding findings, evidence communication is the heuristic way to nurture trustworthiness [72]. For instance, the government could consider using health insurance to balance state finances with individual expenditure. Making vaccine clinical trial data open and transparent is an effective way to assuage public skepticism. To eliminate the strongly-held but flawed cognitive predisposition, the government needs to increase the popularization of public science to popularize the side effects of drugs and strengthen the publicity of all kinds of vaccines. Moreover, previous studies indicated that once the vaccines are available, distributing them would become a problem [73 - 75]. The production capacity of vaccines has also been questioned by scholars. And the looming worry is that new rounds of anti-vaccine and anti-vaccination movements would be sprung up in the backlash of populism [59] and further undermine global efforts to curb the COVID-19 epidemic. Some scholars turn their attention to the disadvantaged groups and believe that the ethical framework needs to be improved to protect those groups’ rights and interests in the process of COVID-19 vaccination [75]. Arguably, affordable and effective vaccines offer a shot of hope for the pandemic, while open-minded and iterative policy fuels public engagement against the pandemic.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

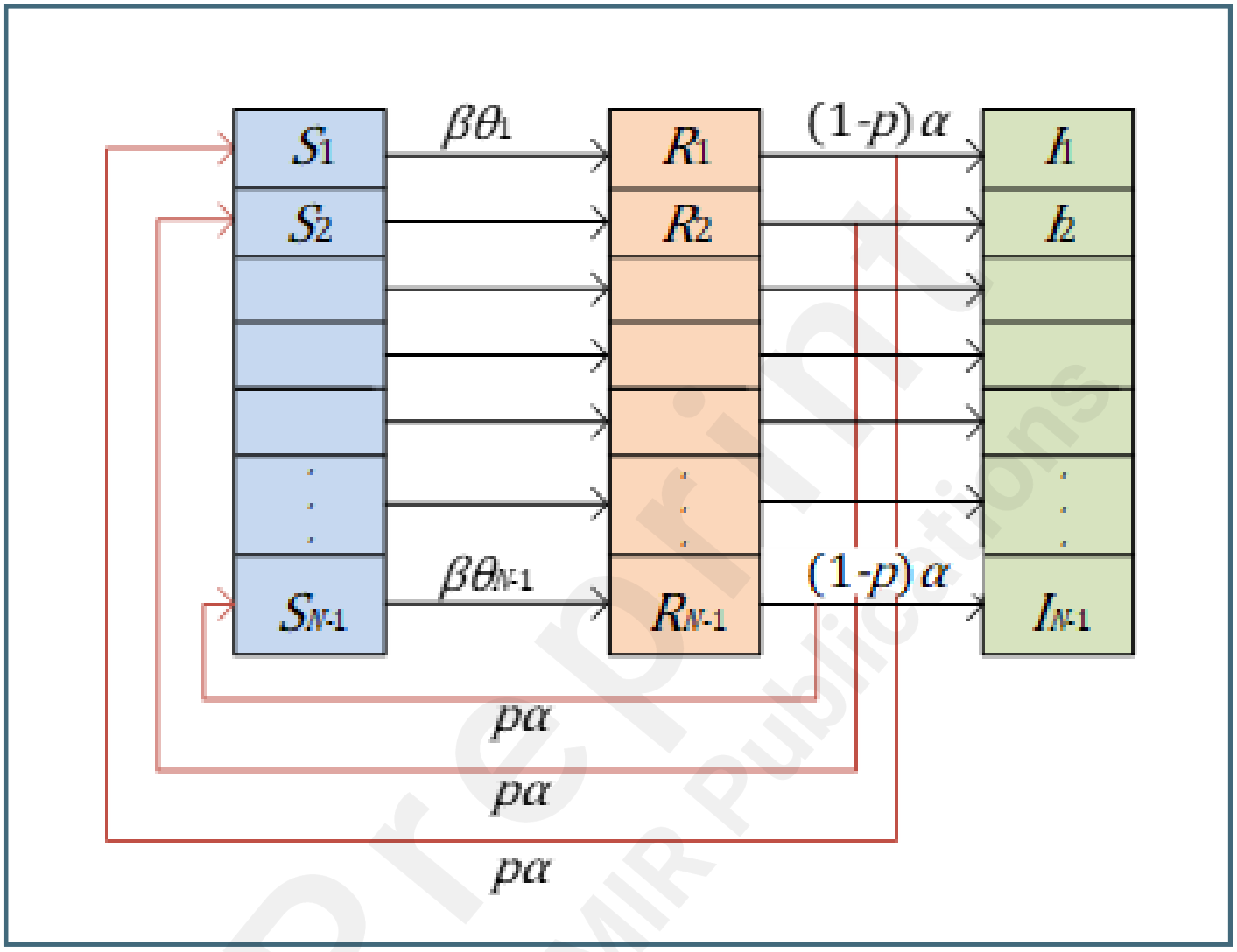
COVID-19: coronavirus disease
WHO: World Health Organization
NLP: natural language processing
RMB: Chinese yuan
AE: Adverse Event

Supplementary Files

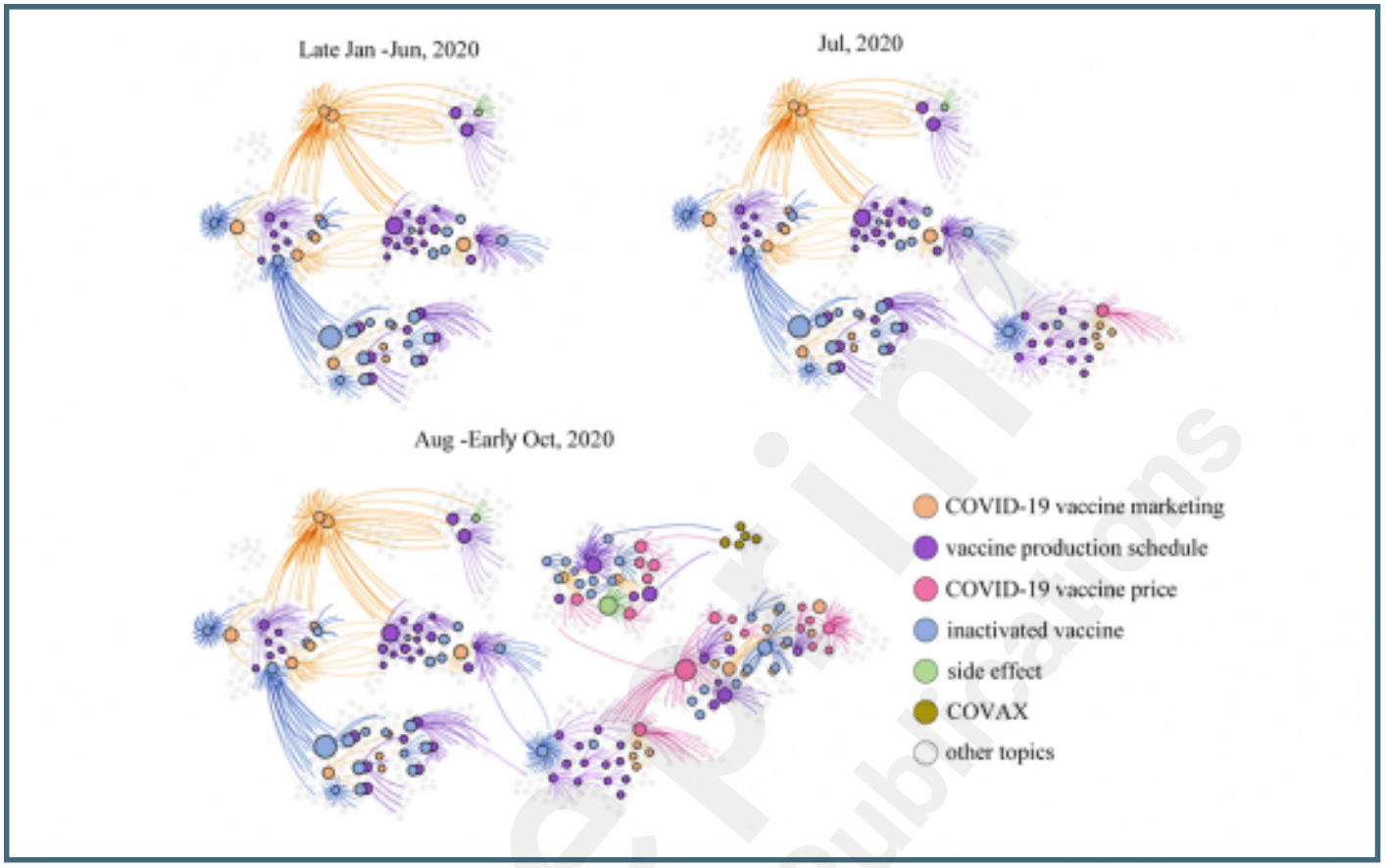
Revised version with tracked changes.
URL: https://asset.jmir.pub/assets/312aa23b73f36883e1614a85d6d6e4a3.docx

Figures

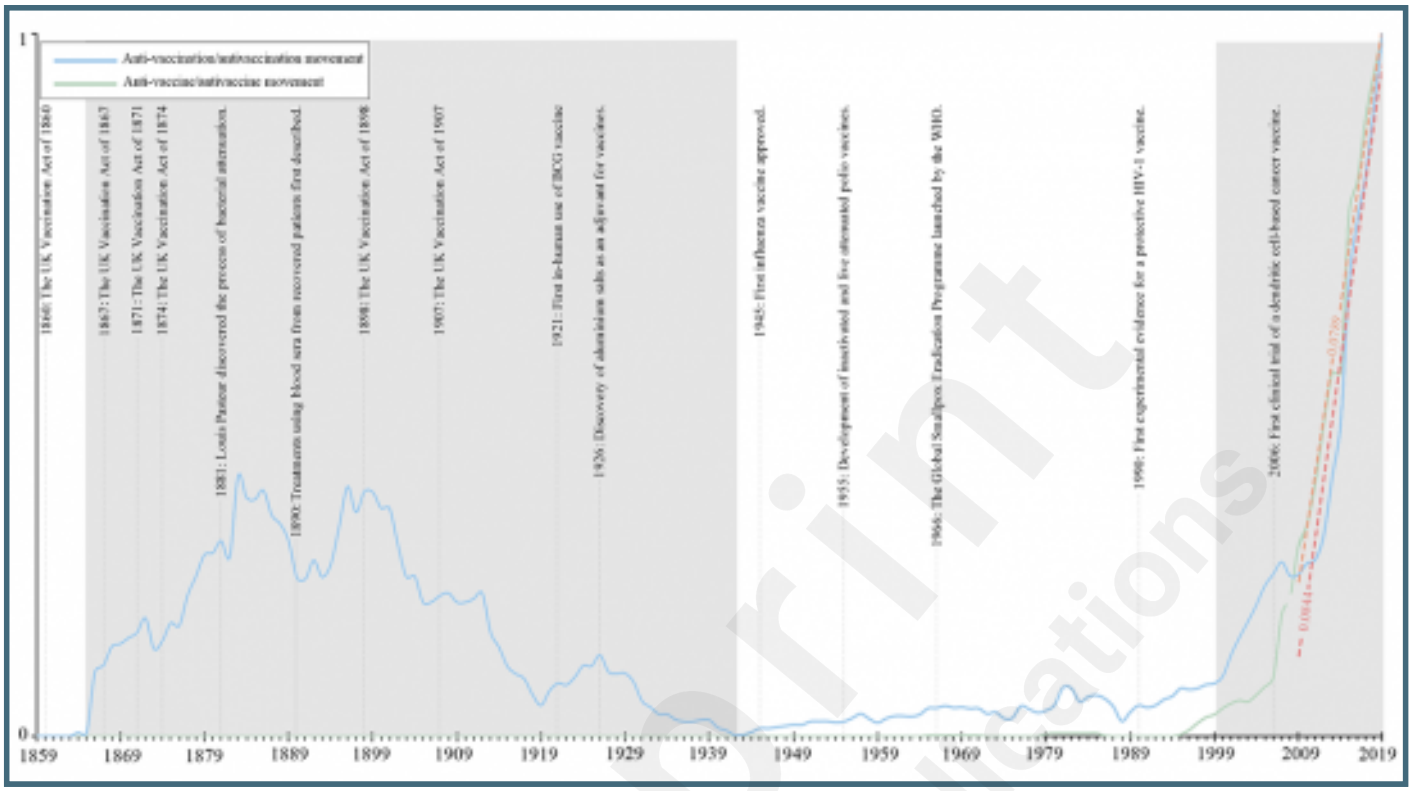
Inspired by infectious disease models, network model diagram of information dissemination is proposed to simulate the transmission of information among the susceptible state (S), the reading state (R), and the immunized state (I).



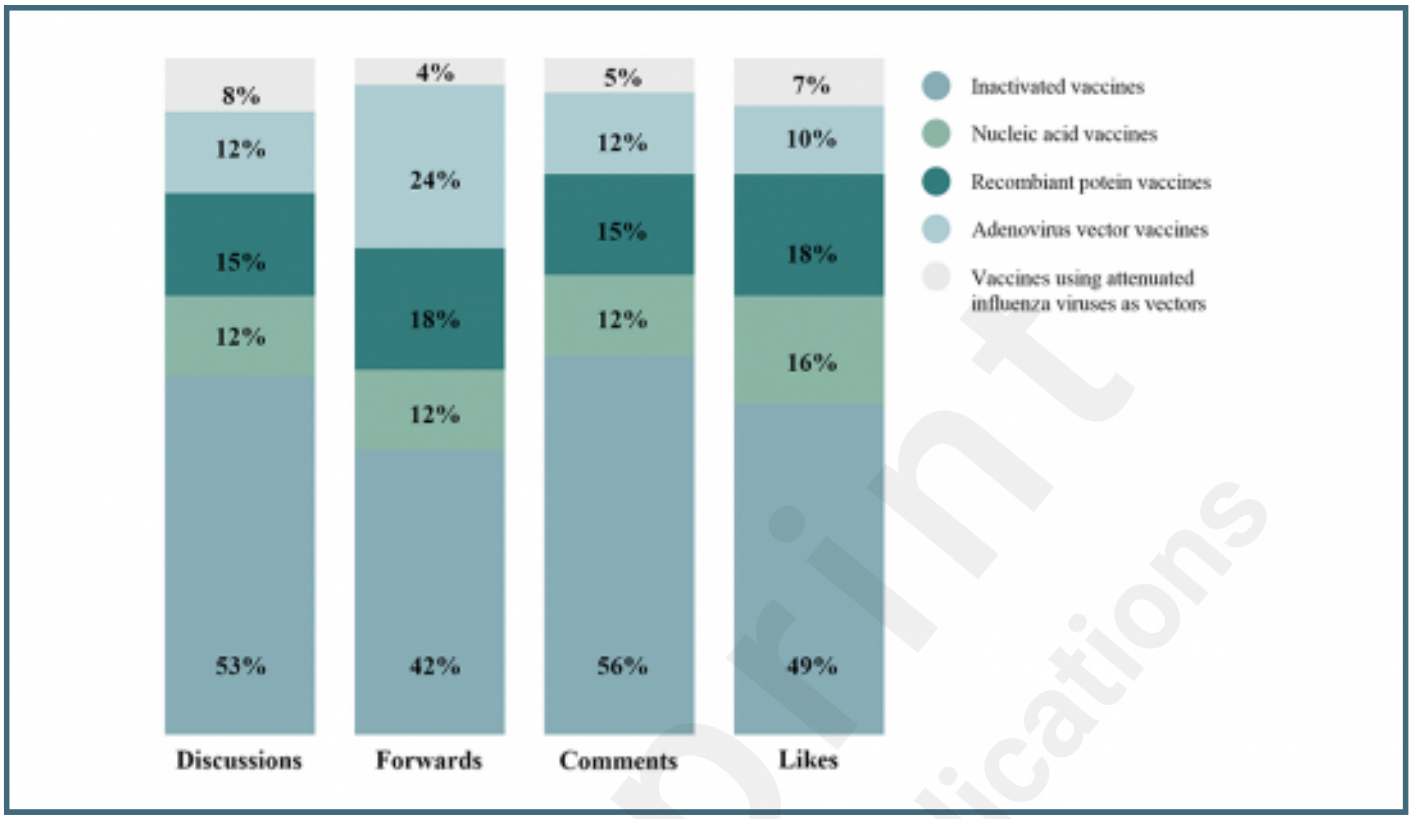
The landscape of public opinion transmission on vaccines-related topics. The seven different colored dots represent the seven main topics. The lines between them represent the mutual influence between them, and the density of the lines represents the degree of influence.



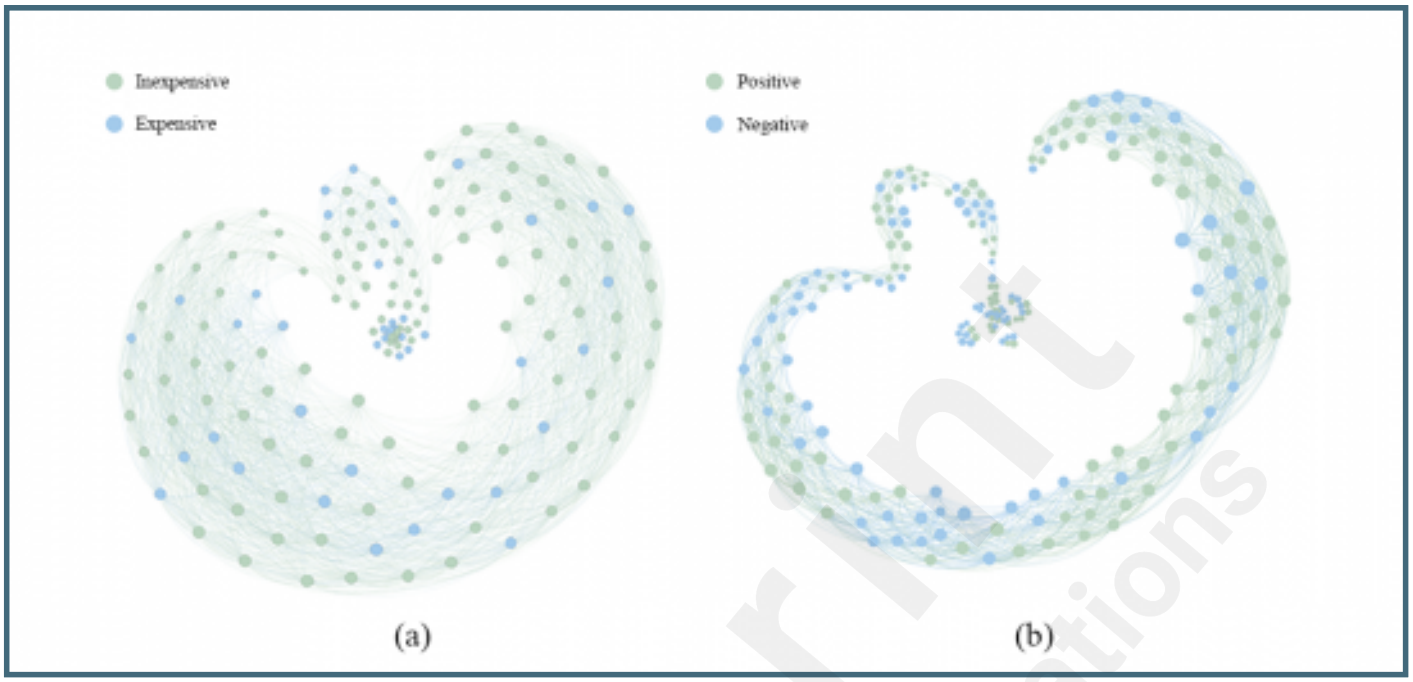
Google Books Ngram Corpus (GBNC) facsimiles word frequencies of “anti-vaccination/antivaccination movement” and “anti-vaccine/antivaccine movement” in English corpus from 1859 to 2019.



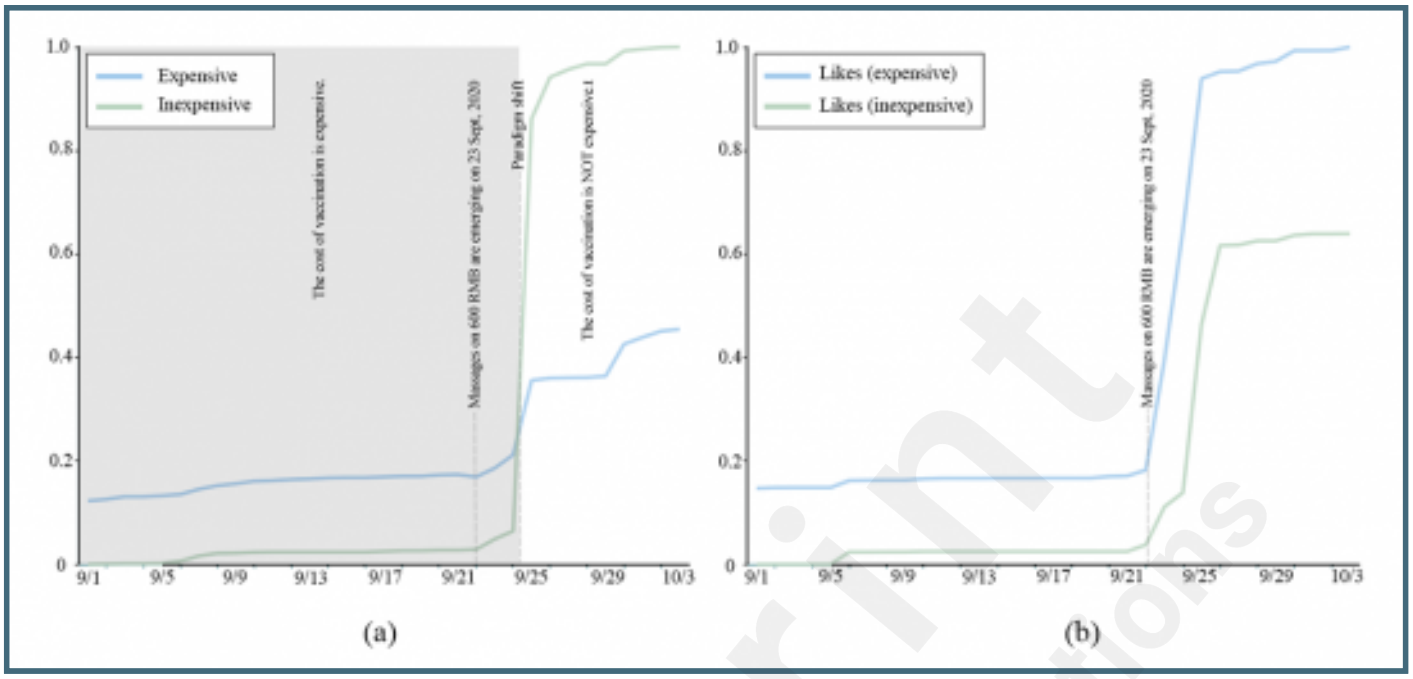
The distribution of netizens' attention to five different types of China-made vaccines.



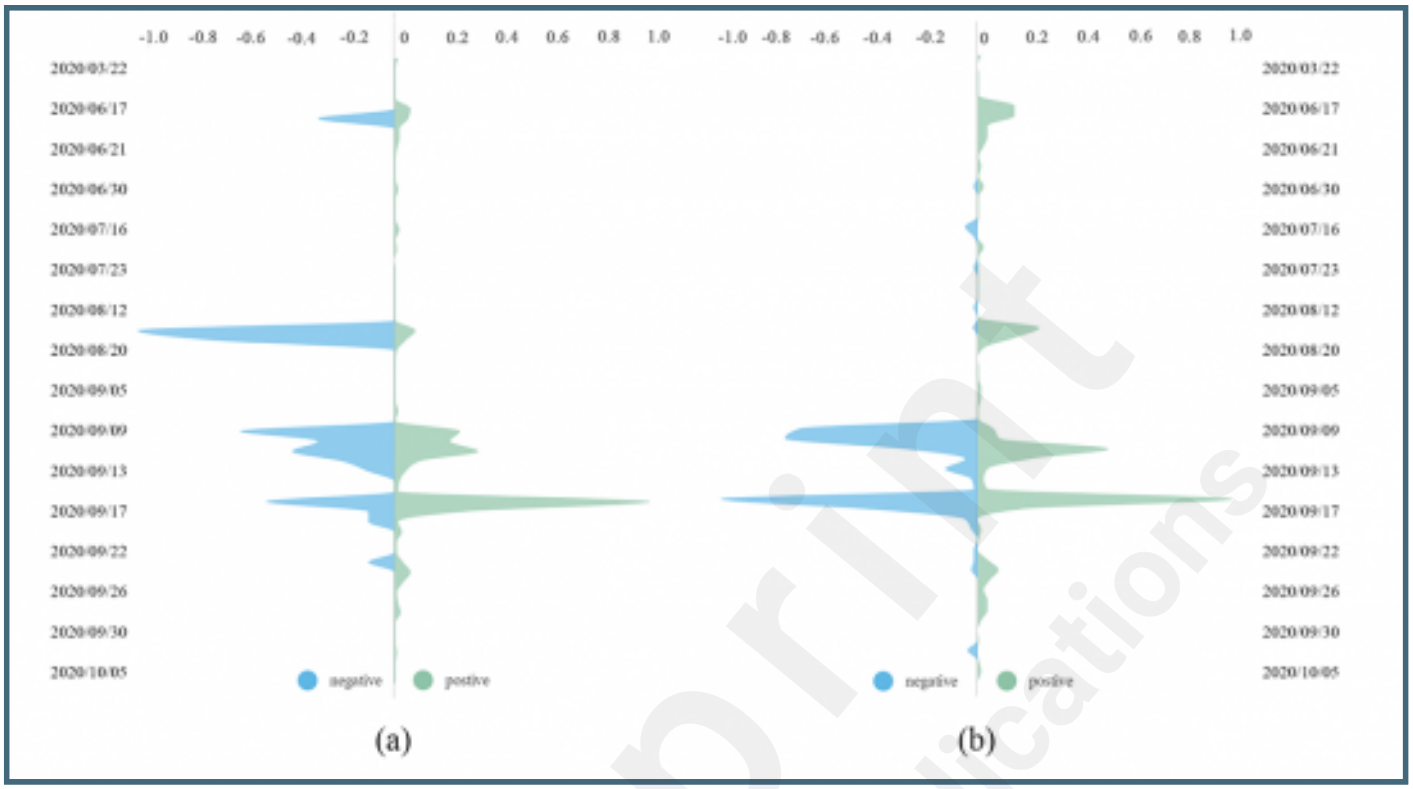
Weibo attitude contagion map: (a) Price; (b) Side effect. Points represent Weibos that appear in the figure in clockwise order, ending with the point at the center of the figure.



The paradigm shift of price tendency.



The collective attitudes towards side effects: (a) the results of the lexicon-based method, (b) the final results coupled with human labeling.



Multimedia Appendixes

Typical topics related to the COVID-19 vaccines, containing the information about topic name recommendation, reading quantity, and date.
URL: https://asset.jmir.pub/assets/488c2e304f7024177c7181e392a75fad.docx

Price polarity table.
URL: https://asset.jmir.pub/assets/333d58fd7584a885024c8a258e000d62.docx