Viral misinformation and echo chambers: the diffusion of rumors about genetically modified organisms on social media

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Abstract

Purpose – The spread of rumors on social media has caused increasing concerns about an under-informed or even misinformed public when it comes to scientific issues. However, researchers have rarely investigated their diffusion in non-western contexts. This study aims to systematically examine the content and network structure of rumor-related discussions around genetically modified organisms (GMOs) on Chinese social media.

Design/methodology/approach – This study identified 21,837 rumor-related posts of GMOs on Weibo, one of China's most popular social media platforms. An approach combining social network analysis and content analysis was employed to classify user attitudes toward rumors, measure the level of homophily of their attitudes and examine the nature of their interactions.

Findings – Though a certain level of homophily existed in the interaction networks, referring to the observed echo chamber effect, Weibo also served as a public forum for GMO discussions in which cross-cutting ties between communities existed. A considerable amount of interactions emerged between the pro- and anti-GMO camps, and most of them involved providing or requesting information, which could mitigate the likelihood of opinion polarization. Moreover, this study revealed the declining role of traditional opinion leaders and pointed toward the need for alternative strategies for efficient fact-checking.

Originality/value – In general, the findings of this study suggested that microblogging platforms such as Weibo can function as public forums for discussing GMOs that expose users to ideologically cross-cutting viewpoints. This study stands to provide important insights into the viral processes of scientific rumors on social media.

Keywords Rumor, Genetically modified organism, Echo chamber, Chinese social media, Comments

Paper type Research paper

The spread of rumors about scientific topics has posed a persistent threat amid the rise of social media (De Domenico *et al.*, 2013). As people increasingly rely upon social media for science information to inform their decisions, the rapid propagation of rumors across social networking sites have considerably increased the chances of citizens to be misinformed about science (Bessi *et al.*, 2015). Although researchers have often investigated the diffusion of scientific rumors in the US and European settings, very few have examined its diffusion in non-western contexts. Such research is necessary, however, not only because rumors are diffused and assessed within communities in distinct cultural contexts, but also because information and its judgment are socially located and not merely the result of individual decisions (Fine, 2007). Researchers to date have focused on the characteristics of audiences and their critical ability to assess rumors and tend to downplay how communal judgments shape individual responses within particular cultural contexts. To narrow those gaps in the literature, we set out to examine, from a social network perspective, how scientific rumors spread on Chinese social media, namely, on Weibo, the Chinese equivalent of Twitter. In particular, we scrutinized how social media users responded to rumors – disseminated them,

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supported them, or denied them – about genetically modified organisms (GMOs) spread in discussions about GMOs on Weibo.

Despite being recognized for its tight control over China, the Chinese government has granted its citizens great latitude when it comes to GMOs. As a result, Chinese social media networks are rife with fake news and anti-GMO fervor, spread by a wide range of sources, including celebrities, Maoists and nongovernmental organizations (Chow, 2019). More recently, as part of a concerted effort to combat skepticism and hostility toward GMO foods, Chinese scientists have begun turning to social media such as Weibo to discuss GMOs. As China's most popular microblogging platform, Weibo has become widely known as a platform on which laypeople as well as experts, media professionals and paid communicators debate and deliberate upon GMOs (Xu *et al.*, 2018).

Studies on the consumption of science misinformation in western contexts (e.g. Bessi *et al.*, 2014) have suggested that in environments where misinformation is pervasive, users' aggregation around shared beliefs may make sustained exposure to misleading information a determinant of its virality. Social media users tend to gravitate toward information that validates their belief systems and to form echo chambers – homophilous communities of the like-minded – that reinforce a shared narrative (Colleoni *et al.*, 2014). Existing literature has shown that homophilous communities in online social networks influence opinions about and reactions to many issues of public concern, including political disclosure (Shin *et al.*, 2017), vaccination (Schmidt *et al.*, 2018), traditional Chinese medicine (Chen *et al.*, 2018) and climate change (Williams *et al.*, 2015). In contribution, we sought to identify whether such echo chamber effects exist in users' responses to GMO-related rumors on Chinese social media.

Above all, our main research objective was to examine the echo chamber effect in the diffusion of GMO-related rumors. This could be achieved through an improved understanding of the community structure of the rumor diffusion network and the nature of users' interactions between and within communities. Using an approach combining social network analysis, manual content analysis and automatic text analytics, we mapped the structure of Weibo users' interaction networks, measured the distribution of their attitudes in those networks and examined the content and nature of their interactions. Our aim was to characterize the relationship between the virality of scientific rumors and users' patterns of information consumption on social media. The results of our work stand to provide important insights into the viral processes of scientific rumors on social media.

The controversy over genetically modified organisms (GMOs) in China

Chinese consumers have long relied on traditional media – TV, newspapers and radios – as major sources of information about GMOs (He *et al.*, 2015; Ho *et al.*, 2006), the government-controlled coverage of which has been overwhelmingly enthusiastic and rarely critical (Liu and Cong, 2014). In a study on two state-owned newspapers from 2002–2011, Du and Rachul (2012) suggested that Chinese reports on genetically modified (GM) crops had emphasized the benefits of transgenic organisms and seldom portrayed GM crops in a negative light. However, given the rising amount of information available online, scandals about poisoned food have unsurprisingly abounded on social media, and implausible-sounding claims from a vocal minority of GMO critics have gained traction within China's social media networks (Cao, 2018). Indicating the influence of such (mis)information, 46.7% of the respondents in a recent China-wide survey espoused negative views on GMOs, but most of their doubts about the safety of GM foods were based on false information (Cui and Shoemaker, 2018).

Much of the controversy surrounding GM foods in China concerns their possible risks to human health, and research has shown that mistrust in governmental regulation and a lack of scientific knowledge have exacerbated negative public perceptions of GMOs (Gaskell *et al.*, 1999). The survey results show that consumers were not only largely unfamiliar with GM

technologies and their potential benefits but also skeptical of scientists and the government when it comes to GMOs (Cui and Shoemaker, 2018). Although China initially pursued relatively aggressive policies for the development of biotechnology and the government's enthusiasm for GM technology has not waned, Chinese authorities have so far failed to weigh in on the very public debate over such technology's safety (Ji *et al.*, 2019). The chasm of credibility and lack of any trusted referee make it nearly impossible for the public to distinguish rumor from fact, and the public's ignorance about scientific knowledge in the first place has contributed to the virality of rumors about GMOs on social media (Du and Rachul, 2012).

Rumor diffusion and the echo chamber effect

Rumor can be defined as unverified information containing instrumentally valuable statements of public concern (DiFonzo and Bordia, 2007). Although its precise definition continues to vary among scholars, rumors are widely considered to be stories or statements widely disseminated without confirmation or certainty as to their factuality. Rumors can be either true or false, and their distinct stylistic dimensions can prompt different patterns of diffusion. Similarly, classifying rumors as either true or false, Vosoughi *et al.* (2018) examined rumor cascades on Twitter to find that rumors identified as false spread more rapidly than ones identified as true. In view of those findings, demonstrably false rumors may be especially provocative and interesting.

In recent scholarly work on rumors, researchers have probed the spread of single and multiple rumors about a variety of topics, developed theoretical models of rumor diffusion as well as methods of detecting rumors and performed interventions intended to curb the spread of rumors (Ciampaglia *et al.*, 2015; De Domenico *et al.*, 2013; Gupta and Kumaraguru, 2012; Tambuscio *et al.*, 2015). Although insightful, the existing literature on rumors has largely focused on individual differences in responding to rumors while ignoring the context of the communities in which rumormongers are embedded. Existing studies of rumors suggest that what individuals believe often relates to their local network (DiFonzo *et al.*, 2014). More specifically, individuals make judgments according to the standards that they share with the people around them, and such communities of judgment provide the basis for whether individuals view the decisions of their in-group as legitimate (Difonzo, 2018). Likewise, early research on rumors revealed that the content of rumors was closely linked to social boundaries in offline contexts, and divisive rumors can demographically or socially split individuals and groups (Fine, 2007). As a case in point, rumors spread among women about being attacked by male sexual predators have been shown to polarize men and women (Fine, 2007). In online contexts, the activation of rumors was found to be driven by social reinforcement in the neighborhood (De Domenico *et al.*, 2013). An individual is more likely to spread a rumor if most of his or her friends are tweeting the rumor repeatedly.

From a social network perspective, communities operate as subgroups or clusters in which nodes are substantially more connected to one another than to nodes outside the network (Wasserman and Faust, 1994). The existence of clusters has been understood as evidence of *echo chambers*, in which individuals tend to preferentially connect to the nodes within a cluster and form an ideologically homophilous community (Bessi *et al.*, 2015; Schmidt *et al.*, 2017). In recent work, researchers have found empirical evidence about the formation of echo chambers on social media (e.g. Bessi *et al.*, 2015; Medaglia and Yang, 2017; Schmidt *et al.*, 2017; Schmidt *et al.*, 2018). For instance, by tracking several years' worth of Facebook data to investigate whether users become polarized on the social media platform, Schmidt *et al.* (2017) revealed that the consumption of information on Facebook is dominated by the echo chamber effect as well as that users tend to visit very few pages and to create distinct communities.

Previous research has pointed out the link between the phenomena of echo chamber and rumor diffusion (Törnberg, 2018). Homogeneous clusters of users self-select their social

networks because of confirmation bias and selective exposure, which provide fertile ground for rumors to thrive. Increased polarization, together with the propagation of misinformation through social networks, has thus drawn increasing scholarly attention. A large-scale analysis of rumor-related tweets and retweets found that rumors disseminated by echo chamber members spread faster and are more viral than those that are not disseminated by echo chamber members (Choi *et al.*, 2020). Schmidt *et al.*'s (2017) study of news consumption on Facebook showed that rumor diffusion was mainly driven by the polarization of users on specific topics rather than the lack of fact-checking online.

Existing studies have shown that the formation of echo chamber on social media varies by platform (e.g. social medium or news medium) and type of social networks (e.g. friendship network or information network). Echo chamber effect may dominate in friendship networks (e.g. Bakshy *et al.*, 2015; Schmidt *et al.*, 2017) but is less obvious in information networks (e.g. Colleoni *et al.*, 2014; Williams *et al.*, 2015). Microblogging websites such as Twitter and Weibo are both a social medium and a news medium (Kwak *et al.*, 2010). Considering all those trends and findings, in our study, we investigated whether "homophilous communities" also exist in discussions of GMO rumors on Weibo. Instead of just focusing on one type of network, we examined the community structure in both user interaction- and topic-based networks. To guide that trajectory of our research, we devised the following research question:

RQ1. To what extent do users' discussions involving rumors about GMOs on Weibo resemble echo chambers?

Interaction between communities: like-minded and cross-cutting discussions

As Bruns (2017) has pointed out, the boundary for echo chamber is not simply whether social (media) networks exhibit clustering tendencies, but to what extent such communities prompt the exclusion of outsiders. In response, some researchers have found highly segregated communities on social media, whereas others have shown that viral information on social media can permeate into different communities (Weng *et al.*, 2013). Reflecting the latter view, Holbert *et al.* (2010) have concluded that the extent to which social media users deliberately avoid dissonant views online has been exaggerated in research. Altogether, it seems that interactions on social media can generate homogeneous groups but do not necessarily shut out ideologically incongruent opinions (Vaccari *et al.*, 2016). Compared with offline networks, online networks are thought to expand exposure to more diversified information. Because social media afford connectedness among individuals with otherwise weak ties (De Meo *et al.*, 2014), their users are likely to encounter novel viewpoints unlike what commonly circulates in more closely knit social circles (Kim *et al.*, 2013).

Social media also afford the possibility of being inadvertently exposed to different views (Brundidge, 2010). In particular, Weibo as a news medium (Kwak *et al.*, 2010) supports the formation of information networks, in which plenty of weak ties and even hidden links exist. Briefly, *weak ties* refer to a person's relatively distant acquaintances who are likely to differ from him or her, whereas *hidden links* are relationships formed because of a shared interest or co-membership on a social media platform (Huberman *et al.*, 2008). In both cases, the existence of long-distance affiliations facilitates the inadvertent exposure to heterogeneous information and opinions (Brundidge, 2010; Colleoni *et al.*, 2014). Accordingly, Lev-On and Manin (2009) have described online communication as a "mixed blessing" in light of its deliberative affordances, in that it provides both "unintentional exposure to opposing views, as well as 'drivers' that channel users away from opposing views" (p. 105). Interactions among echo chamber members are likely to amplify and reinforce opinions shared, whereas interactions with antagonistic viewpoints may lead to attitudinal change or intensify the controversy (Bonchi *et al.*, 2019; Vaccari, 2013).

Despite all those research efforts, scholars have yet to examine interactions among counter-attitudinal groups in the context of online science communication. Nevertheless, it is

worth characterizing such interactions, which, in China, are readily available within GMO-related online discussions. In that case, investigations should address the extent to which cross-cutting exchanges occur in the diffusion of rumors about GMOs and whether conversations about such a shared public concern facilitate the exchange of opinions across communities. On the latter point, studies addressing similar topics such as climate change (Williams *et al.*, 2015) and traditional Chinese medicine (Chen *et al.*, 2018) have suggested that conversations on social media do not facilitate cross-cutting exchange. Considering all of the above, we formulated a second research question to guide our study:

    RQ2. To what extent do Weibo users engage in cross-cutting exchanges in response to rumors about GMOs?

In addition to quantifying the structural aspects of interactions between communities, we investigated the nature and content of the discussions between and within communities. A comment can convey support or disapproval. If the comment clearly communicates and substantiates its claims, it is more likely to exert an influence on the deliberative potential of an online discussion. In research addressing users' online comments, scholars have focused on information-seeking and information-sharing behaviors and even the nature of affective factors such as emotions and feelings. For instance, categorizing users' comments on Twitter posts with rumors as emotion-related, information-related, deliberative or calling for action, Chua *et al.* (2017) found that most discussions were emotion- or information-related ones. Along similar lines, Zhang *et al.* (2013) have suggested that users' interactions in a Facebook diabetes group were structured around information, emotion and community-building. In one of the rare studies on interactions between segmented communities, Zollo *et al.* (2015) analyzed and compared emotions in debates on Facebook about science versus conspiracy theories. They found that the more that users engaged in discussions, the more they tended to express negative emotions.

In other research, the anonymity of the digital environment proved able to lessen the quality of online comments (e.g. Rowe, 2015). Uncivil, hateful and prejudicial discourse was more likely to surface when users were engaged in conversations about highly polemic issues (Berg, 2016). Investigating like-minded discussions in a study using online investment discussion boards, Tang *et al.* (2017) found that skewed assessments, exacerbated by the insular nature of the online community and its social structure, resulted in underperforming investment advice. With respect to cross-cutting discussions, empirical evidence suggests that members of different communities may frequently retweet each other's posts, and that rational or meaningful conversations between communities seldom occur (Chen *et al.*, 2018). Moreover, exposure to disagreeable, uncivil talk about politics induced anger and aversion, which in turn reduced satisfaction with online political discourse (Gervais, 2015).

In our study, we first classified Weibo users' comments on posts containing GMO-related rumors into supporting and dissenting comments. Such comments could be facts or emotional judgments implying positive or negative preferences concerning the issue at hand. Thus, guided by two more research questions, we examined the extent to which supporting and dissenting comments were respectively related to emotions, related to information or uncivil:

    RQ3. What is the nature and content of Weibo users' comments on GMO rumor posts in terms of information seeking and sharing, emotional expression and level of incivility?

    RQ4. Do supporting and dissenting comments differ in their content-related features (i.e. information seeking and sharing, emotional expression and level of incivility)?

Method

Data collection
Our project focused on scientific rumors about GMOs that circulated on Weibo in 2018. Using the term "genetically modified" in a search on Weibo, we identified 139,319 posts addressing GMOs published from January 1 to December 31, 2018. Next, we created a library of rumors about GMOs by collecting rumors from websites that had already published rumors about GMOs. Two research students were recruited and educated about GMOs. We randomly selected 2% of the collected posts and asked the coders to classify 500 of them as either rumors or non-rumors. The coding achieved a Cohen's kappa (κ) value of 0.95. Disagreements among coders were resolved through discussion, and the coders coded the rest of the data separately. After integrating their coding results and fact-checking online content, we compiled a list of keywords related to rumors about GMOs. Trigram or bigram phrases were combined manually by the researchers, with the aim to identify as many rumor-related messages as possible. Using the rumor-related keywords and phrases as seeds, we identified 21,837 rumor-related discussions (15.7% of all GMO-related messages), including original posts and reposts.

To exclude rumors of relatively small size, we selected original posts ($n = 345$) that had received more than 20 comments (Guo *et al.*, 2018; Shin *et al.*, 2017). This subset of rumors was then coded for veracity by two researchers. We searched for reliable sources to support our coding decisions and resolved disagreement through discussion. We coded each rumor as a "true rumor" if delivered information reflects scientific evidence ($n = 103$, 29.9%) or a "false rumor" if what it described is unlikely or untrue ($n = 227$, 65.8%). Otherwise, 15 rumors (4.3%) were classified as "unclear," because no evidence could firmly support or refute the content.

To address *RQ3* and *RQ4*, we randomly selected 20 of the 345 rumors and coded the attitude of their comments ($n_{\text{comment}} = 3,170$). Of those 20 rumors, 13 were classified as true rumors, five as false rumors and two as being unclear. All comments on the 20 rumors were classified by two coders as: endorsing (i.e. comments that repeat or confirm the original post), rejecting (i.e. comments that deny or reject the original posts) or unclear (i.e. comments without a clear attitude). We chose those categories to span a continuum of views and avoid ambiguity between categories. Presented with both the comment and the original post, two coders coded the comments into three categories based on the mentioned coding scheme. We tested the intercoder reliability and found a κ value of 0.90. Based on the results of coding, users' attitudes toward GMOs were classified as supportive, opposed or unclear.

To compare the content-related features of the endorsing and rejecting comments, we coded the comments as emotional (i.e. the comment contains affective expression), information-oriented (i.e. the comment provides or requests additional information) or uncivil (i.e. the comment is abusive, threatening or prejudiced against others). This categorization was not mutually exclusive. Intercoder reliability test found κ values ranging from 0.81–0.93, all of which were acceptable and suggest that the results of classification were robust. Last, we used the automated coding in the software *TextMind* (Gao *et al.*, 2013) to identify positive and negative emotions in the comments.

The co-commenter network
To explore patterns of community structure and membership related to the rumors, we established an affiliation network between rumors and users. In social network analysis, affiliation networks are two-mode networks that map the relationship between two types of nodes (Wasserman and Faust, 1994). In our study, the first type of nodes was Weibo users, whereas the second was GMO-related rumors. Our two-mode network consisted of 345 rumors and the 25,126 users who commented on them. Next, we transformed the two-mode

affiliation network into a single-mode network such that if a user commented on rumors i and j, then rumors i and j were considered to have a tie. The rumor co-membership network was a non-directed and weighted network. By transforming the rumor-to-user affiliation network into a single-mode rumor-to-rumor network, we were able to infer the extent to which false rumors were connected to true rumors in discussions.

To identify the community structure of the rumor co-membership network, we calculated the assortativity coefficient of the network based on rumors' veracity. The assortativity coefficient measures the level of homophily of the network based on a node-level attribute (Newman, 2002) – essentially, the Pearson correlation of behaviors between linked nodes (Aral et $al.$, 2009). The assortativity coefficient r falls within the range $-1 \leq r \leq 1$ and is defined as:

$$r = (\text{sum}(e(i,j),\ i) - \text{sum}(a(i)b(i),\ i))/(1 - \text{sum}(a(i)b(i),\ i)),$$

in which $e(i,j)$ is the fraction of edges connecting vertices i and j, $a(i)$ is sum$(e(i,j),j)$ and $b(i)$ are sum$(e(i,j),\ i)$.

The comment thread network

To explore the community structure of the discussions about GMO rumors on social media, we constructed a comment thread network such that if user i commented on a rumor-related message posted by user j, then we acknowledged a link between i and j in the network. The rumor discussion network was a directed, weighted network. This network mapped the relationship between 1,631 users involved in posting and commenting on the 20 selected rumors about GMOs.

We identified influential users in the discussion network by using multiple social network metrics, including number of fans ($>12,000$, $n = 88$), indegrees (>4, $n = 57$) and k-core members ($k = 4$, $n = 64$). *Number of fans* measured the populousness of the user's direct audience, whereas *indegrees* was the total number of comments received by the user in the rumor diffusion network. Last, used to gauge so-called "coreness," k-*core* was used as a measure to identify minor but interconnected core entities within a network. To be included in the k-core, every node has to be connected to at least k other nodes in the group (Hanneman and Riddle, 2011). Because researchers have suggested that the influence of a user in a network is a multidimensional construct that should be measured with multiple indexes (e.g. Wang et $al.$, 2016), we used the three measures to identify influential users in social networks.

To measure the level of attitude-based homophily in the user interaction network, we also calculated the assortativity coefficient. Another way to examine the echo chamber effect is by assessing heterogeneity, defined as the balance between members holding supportive and opposing perspectives (Williams et $al.$, 2015) and measured as:

$$H = 1 - |s - o| / |s + o|,$$

in which s is the observed frequency of supporters, and o is the observed frequency of opponents. That measure returns a value on a linear scale from 0 (i.e. perfect homogeneity, in which only supporters or opponents exist) to 1 (i.e. perfect heterogeneity, in which equal proportions of supporters and opponents exist).

Results

We identified 345 Weibo posts from 2018 containing GMO rumors that had received more than 20 comments. Among them, we found 103 true rumors (i.e. delivering scientific information), 227 false rumors (i.e. delivering unlikely or untrue information) and 15 unclear

rumors. Table 1 listed some examples of the three types of rumors. The average number of replies was 128.25 (SD = 255.91) for the false rumors and 113.56 (SD = 234.19) for the true ones.

The co-commenter network
The rumor co-commenter network was a small but dense network, with 345 nodes and 761 co-memberships (density = 0.030). The most centric rumors were connected to 18 other rumors in the network, which implies users interested in GMOs screened a large number of rumors at once. As shown in the rumor co-commenter network in Figure 1, the connections between the true and false rumors were intense, and no clear separation formed between their corresponding discussion communities. On the contrary, overlaps emerged between the communities circulating true and false rumors. The rumor co-commenter network's assortative coefficient, indicating the extent to which nodes were clustered based on veracity, was 0.15. That result suggests that the network had a low level of veracity-based homophily, and that users tended to comment on both true and false rumors.
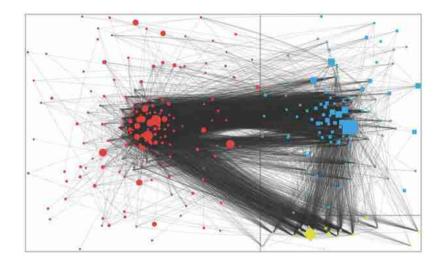
The comment thread network
The comment thread network, though a sparse one with 1,631 nodes and 3,170 edges (density = 0.001), nevertheless represented a cohesive community, with values of reciprocity (0.097) and transitivity (0.003) that were higher than those in networks previously examined (e.g. Peng *et al.*, 2016). Such results indicate that users grouped by the GMO-related topic were tightly connected with each other. At the same time, the assortative coefficient of the comment thread network based on users' attitudes toward GMO was 0.13, which implies a low level of polarization among users. Together with what the homophily analysis of the rumor co-commenter network revealed, such findings suggest a low level of the echo chamber effect in discussions about GMOs on Weibo.

To understand the distribution of opinions expressed about GMOs on social media, we analyzed the distribution of attitudes among influential users identified by number of fans,

Category	Search keyword	
True rumor	Genetically modified and sterilization	[Genetically modified foods lead to sterilization] is actually a conspiracy theory, and crossbreed is also a type of genetic modification
False rumor	Genetically modified and tumor	The incidence of tumors in Chinese children is increasing by 2.8% per year. In western countries, tumor is a disease that mainly occurs in elderlies over 50 years old. Nowadays, after the high incidence of tumor in young people, it starts to increase in children in China. The reason is because of the very difference of China from the world: China is the only country on the planet where most people eat genetically modified foods
	Genetic modification and infertility	Genetic modification can cause infertility, mules are the genetically modified result of horses and donkeys, and few of them are fertile. The health of the next generation lies in your choice!
Unclear	Genome editing and detect	[New genetic modification methods such as genome editing cannot be detected] Whose right to interpret the data after detecting genetically modified foods?

Table 1.
Example of true, false and unclear rumors

Note(s): Coding of rumors' veracity was conducted by the researchers referring to articles and publications from reliable sources, such as Chinese Academy of Science (http://www.cas.cn/), Ministry of Agriculture and Rural Affairs (http://www.moa.gov.cn/) and Guokr (a popular science website: https://www.guokr.com/)

indegrees and *k*-core. The heterogeneity score for the full network was 0.41, and for subgroups defined by number of fans, indegrees and *k*-core were 0.75, 0.71 and 0.51, respectively. Overall, opposing views dominated the discussions about GMOs, especially among users in the entire network and the subgroup defined by *k*-core. We found that opponents significantly outnumbered supporters in both of those groups (Figure 2).
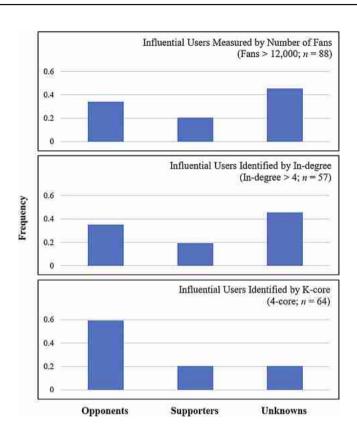
As shown in Figure 3, the discussion networks exhibited segregations of users (i.e. nodes) according to their views on GMOs, presented by three colors. Whereas GMO opponents formed the majority in the full networks (Figure 3a), some supporters were located at the core of the networks as well (Figure 3b–d). More interactions (i.e. links) occurred among like-minded users (29.4%), although less often between users espousing different views (13.9%). In other words, the discussion network demonstrated homogeneity as well, which suggests that individuals on social media tend to discuss topics concerning GMOs with others similar to them. Among other results, half of the discussions presented unclear views on GMOs (49.7%), in which only emotions or emojis, mostly negative ones, and hate speech were presented. That finding highlights that a large portion of online discussions about GMOs do not convey meaningful information. In general, as heterogeneity analysis revealed, a mixture of homophily and heterophily emerged in users' discussions concerning rumors about GMOs.
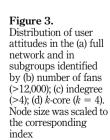
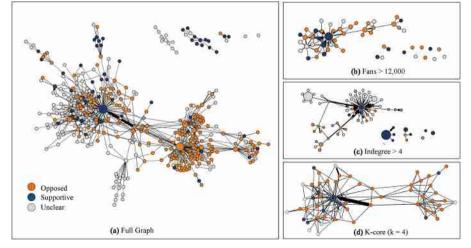*Cross-cutting exchange on genetically modified organism rumors*
To answer *RQ2*, we examined the amount of cross-cutting exchange in users' responses to rumors about GMOs. Our results suggest that users responded to true and false rumors differently; true rumors were more often rejected (21.2%) than false ones (6.5%) but received fewer endorsements (9.3%) than false ones (61.7%) as well.

To elucidate the nature of interactions between members of the discussions about GMOs, we analyzed the content of the discussions (*RQ3* and *RQ4*). Of the 3,170 post-reply interactions, 32.2% ($n = 1,020$) were interactions between like-minded users, 23.2% ($n = 735$) were between users with opposing views and 44.6% ($n = 1,415$) involved at least one user who demonstrated an unclear attitude. The results of an additional one-way analysis of variance showed that cross-cutting interactions generally contained a significantly greater amount of emotions – and more negative ones – as well as information and incivility than

interactions among the like-minded or between users without a clear attitude. At the same time, interactions between like-minded users contained a significantly higher level of emotionality, both negative and positive, as well as incivility than ones between users without a clear attitude. Somewhat remarkably, the interactions between users without a clear attitude contained a higher level of information than ones between the like-minded (Table 2).

Discussion

Our findings contribute to knowledge about rumor diffusion on social media by presenting empirical evidence of the community structure formed within discussions of GMO rumors posted on China's Twitter-like Weibo. We empirically tested the echo chamber effect in shaping social media users' responses to rumors about GMOs in the Chinese context. Our findings suggest that some social media users are substantially more likely to engage with like-minded others. Users active in online discussions of GMOs, either as activists or as skeptics, tended to exhibit strong attitudes, while neutral views were largely absent. Meanwhile, cross-cutting exchange did occur, albeit to a lesser extent than like-minded exchange. In general, our findings confirm that microblogging platforms such as Weibo can also function as public forums for discussing GMOs that may expose users to ideologically cross-cutting viewpoints at times.

The echo chamber effect in rumor diffusion

Our results show that discussions about GMOs on social media are characterized by a weak level of (a) veracity-based homophily in terms of rumor content and (b) attitude-based homophily in terms of users. Moreover, our results reveal the coexistence of like-minded interactions and cross-cutting exchange. Accordingly, some Weibo users are more likely to form cohesive communities that support their views, as consistent with the notion of echo chambers on social media. At the same time, we observed a large portion of users who interacted with others who held different views, which increased the likelihood of cross-cutting exposure overall. Such empirical evidence clarifies insights gained from offline settings (e.g. Huckfeldt *et al.*, 2004; Vaccari *et al.*, 2016), namely, that heterogeneity persists on social media despite the prevalence of homophily.

Previous research addressing a friendship network on Facebook and follower–followee relationships on Twitter suggested strong attitude-based homophily (e.g. Schmidt *et al.*, 2018; Yang *et al.*, 2017). However, our analysis of the rumor co-commenter network found that far weaker homophily exists, at least on Weibo. Microblogging sites such as Twitter and Weibo afford the establishment of social connections as well as information sharing. Users may form strong ties with others whose views are consistent with their own, such as in friendships on Facebook and reciprocal ties on Weibo, but also encounter others with different views via weak ties, including in communities connected by shared interests.

Because increasingly more individuals rely on social media for news and information, the structural features of social and information networks are likely to play an increasingly

		Emotion		Negative		Positive		Information		Incivility	
	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Like-minded	1,020	0.60	0.49	0.33	0.47	0.35	0.48	0.19	0.39	0.43	0.49
Cross-cutting	735	0.69	0.46	0.46	0.50	0.37	0.48	0.64	0.48	0.32	0.47
Unknown	1,415	0.49	0.50	0.25	0.43	0.25	0.43	0.53	0.50	0.50	0.50

Table 2.
Proportion of emotion expression, negative emotion, positive emotion, information-seeking/sharing and incivility in like-minded, cross-cutting and unknown interactions

important role in shaping the diffusion of rumors. Using social media does not seem to diminish the overall diversity of public views on GMOs. Instead of corroborating that people receive only ideologically aligned information or opt out of accessing hard news altogether, our work shows that social media expose individuals to ideologically cross-cutting viewpoints. Counter-attitudinal interactions have implications for attitudes toward GMOs. Existing research has revealed that exposure to a diversity of views is associated with a lower likelihood of holding a polarized view (Levitan and Visser, 2009; Williams *et al.*, 2015), which could prevent the virality of rumor diffusion (Schmidt *et al.*, 2017). Our findings suggest the affordance of microblogging websites to expose individuals to perspectives from the other side and the potential to change attitudes.

Our findings additionally suggest that the interaction networks formed on social media should not be determined based solely on the relationship indicated by reposting or replying. Although most studies on the topic to date have involved using reposts or replies to construct networks, in our study we went a step further by constructing an interaction network with reference to comment-based relationships. Specifically, we constructed a co-commenter network and a comment thread network. Because a comment can often indicate a user's attitude toward the issue at hand, it affords researchers the opportunity to examine the valence of ties in the interaction networks. By examining the valence of comments that bind participants in a network, we found evidence suggesting the existence of cross-cutting exchanges. In other words, the comment space provides a more or less open forum in which users confront or express dissenting views. Knowing that, researchers should begin to incorporate a more comprehensive measurement of interaction networks based on different types of relationships. The method used in this study can be applied to gauge the echo chamber effect and to assess the mechanisms (e.g. cross-cutting exchanges) allowing to break out of the proverbial echo chambers. A practical implication of the finding is that promoting scientific knowledge in the comment section may function to reduce the echo chamber effect on social media.

Attitude heterogeneity among participants and opinion leaders

To examine the polarization of attitudes toward GMOs, we analyzed the opinions of all users as well as opinion leaders identified by different criteria (i.e. influential users) in GMO-related discussions. As a result, we observed strong attitude homogeneity across the network and in four-core network, in which most participants were sceptics. More attitude heterogeneity surfaced among influential users who received more comments and had more fans.

The role of opinion leaders in shaping attitudes toward GMOs merits attention. The two-step flow model of communication (Katz, 1957; Katz and Lazarsfeld, 1955) holds that media influence is exerted via the intermediary actions of opinion leaders who interpret and disseminate new information to others. In our study, we observed that though the most influential users on social media, indicated by number of fans and indegrees, were largely celebrities, news media outlets or governmental accounts, the overall discussion about GMOs was dominated by sceptics. There was a tension of attitudes toward GMOs between traditional opinion leaders and general users on Weibo, which echoes survey findings that Chinese consumers are cautious in trusting the opinion of scientists, news media and governmental organizations (Cui and Shoemaker, 2018). Although traditional opinion leaders have been vocal on Weibo, anti-GMO sentiments fueled by nongovernmental organization media, activists and grass-root exposés and conspiracy theories (e.g. "GM crops are a conspiracy of American imperialism to annihilate Chinese") have spread as a result. Traditionally, the tackling of rumors depends on news media, governments and scientists. The findings suggest that the effectiveness of these traditional opinion leaders in refuting rumor was on the decline. We should instead rely on a wider gamut of gatekeepers

to disseminate GMO-related knowledge and stimulate a dynamic conversation on social media.

Like-minded and cross-cutting interactions: information- or emotion-related?
Our results additionally show that in the cross-cutting interactions, 64% of the messages provided or requested information, which was a significantly higher rate than in interactions among the like-minded (19%). Such empirical evidence was inconsistent with prior studies in the political context (e.g. Rojecki and Meraz, 2016; Shin *et al.*, 2017) and the general context (e.g. Zollo *et al.*, 2015) which found seeking information was largely absent in rumor-related discussions. This inconsistency might be related to the particularity of the Chinese context, in that discussions about GMOs on Chinese social media often involve enumerating facts or providing additional information in debates. The pro-GMO camp often shares and disseminates information on the scientific consensus formed around GM technology, whereas the anti-GMO camp often cites factual evidence that stresses the uncertainties and possible environmental and health risks of GMOs. This finding provides guidelines for the practice of promoting popular science of GMO on social media. Practitioners could provide more reliable sources for fact checking. The evidence-based knowledge of GMOs should be disseminated to restore the public's confidence in science's ability to address public health and environmental concerns.

By comparison, our results included that most like-minded interactions (60%) expressed emotions, and only 19% of like-minded interactions had comments that requested or provided information. Such findings support previous assumptions that interactions between like-minded people tend to reinforce a shared view regardless of the narrative, which may fuel the viral spread of rumors. At the same time, our results also indicate that cross-cutting interactions contain a higher level of incivility and negative emotions than other kinds of interactions. Rational debates about the benefits and drawbacks of GMOs remain an ideal on Chinese social media. Our study contributes knowledge to the literature by distinguishing like-minded from cross-cutting interactions and by examining the nature of those interactions.

Limitation and future work
It should be noted that social media content varies by type, including text, images, audio, video, or a combination. Because the scope of our study was limited to the text, images and videos should be examined in future studies, even if they require a greater variety of analytic methods. At the same time, the discussions that we observed on Weibo represent only a slice of the larger cyberspace in which rumors go viral. It is possible that the discussion and diffusion of rumors are shaped by different types of media platforms and communication, either independently or conjunctly (e.g. other social media platforms, news media websites and private communication). In addition, a longitudinal study of rumor diffusion could illuminate the dynamics of online community formation and conflict resolution. Such research might ask whether cross-cutting interactions reach consensus over time or become segmented as a result of ideological differences. Another question is what the driving factors behind the viral spread of rumors on social media are, both individual- and network-wise. By targeting a longer period in a design that is not cross-sectional, researchers could address those and other lines of inquiry.

Conclusion
One major contribution of this study is that it systematically examined the network structure formed around the discussion of rumors about GMOs on one of China's most popular social media platforms. On the one hand, this study established the existence and extent of the echo

chamber effect in the interaction networks. On the other hand, we found that rumors not only bounced around through these echo chambers. Moreover, Weibo also served as a public forum for GMO discussions in which cross-cutting ties between communities existed. Most studies to date have involved constructing interaction networks based on reposts only, which precludes any further examination of the valence of ties. We constructed an interaction network with reference to comment-based relationships that encompassed two types of networks: the co-commenter network and the comment thread network. Because a comment can often convey a user's attitude, our strategy afforded us the opportunity to examine the valence of users' ties in the interaction networks. We also distinguished like-minded interactions from cross-cutting exchanges, and our findings testified to their coexistence. Our network analysis revealed that though a certain level of homophily existed in the interaction networks, referring to the observed echo chamber effect, Weibo also seemed to serve as a public forum for GMO discussions in which rumors could spread from community to community. A considerable amount of interactions emerged between the pro- and anti-GMO camps, and most of them involved providing or requesting information, which could mitigate the likelihood of opinion polarization. By extension, our findings suggest that microblogging sites such as Weibo have the potential to challenge the flow of rumors. Last, our study revealed the declining role of traditional opinion leaders (e.g. scientists, state media and government institutions) and the lack of alternative sources for fact-checking content on Weibo. Such trends pose the potential concern that rumors about GMOs may more easily go unchecked and viral on Chinese social media. In response, researchers should explore the roles of different types of opinion leaders in rumor diffusion, which could help to guide the development of efficient debunking strategies.

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