(Dis)Information Wars*

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Abstract

Over the past decade, social media platforms have emerged as prominent vehicles for displaying dissent. In response, various actors have increasingly spread fake news on these platforms to impair the opposition—the (dis)information war. We propose a methodology to identify disinformation using network-based characteristics of the news initiators, and use data from Twitter (now X) to assess the effectiveness of this method in limiting the spread of disinformation. We find that it detects at least 85% of verified instances of disinformation without misidentifying any true news, and reduces both account engagement and lifespan of disinformation by at least a factor of two, highlighting the importance of swift discovery of disinformation to interrupt its exponential spread.

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1 Introduction

The introduction of social media platforms has changed the way people consume news. The rapid improvement of big data technologies has enhanced access to news and facilitated public discourse without the intervention of traditional gatekeepers. However, these advancements have also made social media platforms fertile ground for the spread of disinformation. Many adversarial players have exploited the unfiltered nature of the Internet to their advantage, attempting to influence elections overseas or launching disinformation campaigns to benefit their cause. As a result, disinformation has become a critical threat to democratic discourse and social stability. To address this growing problem, this paper introduces a novel "network-based" approach, offering a proactive solution to combat disinformation in the digital age.

The widespread public access to multiple information sources has significantly diminished the effectiveness of direct propaganda tactics. In response, governments and other entities have moved beyond traditional propaganda, engaging in what we term a *"disinformation war."* These campaigns utilize imposter accounts on social media platforms to spread false narratives while masquerading as ordinary, unbiased users (Hynes, 2021). Unlike classic propaganda, the goal is not to control the narrative but to sow confusion, discredit opposition, and disrupt the flow of legitimate information. This approach has several advantages: it does not require force, is difficult to trace, and disrupts the flow of information, thereby derailing opposition without overt aggression.[1]

Current approaches to tackling disinformation primarily rely on real-time content moderation and ex-post fact-checking. However, these methods have significant limitations. Real-time fact-checking or content moderation is time-consuming and costly, often allowing disinformation to go viral before it can be addressed. Moreover, studies have shown that ex-post debunking has limited effectiveness in debiasing audiences who have been exposed to disinformation.[2]

In this paper, we propose a novel *network-based approach to disinformation labeling* to impede the disinformation war through ex-ante content moderation. Our method shifts the focus from content analysis to the identification of accounts likely to initiate disinformation campaigns. This ex-ante strategy aims to flag potential disinformation before it gains traction, offering a proactive solution.

[1] This aligns with the recent shift in dictators' tactics, wherein they exert control over the public through the manipulation of truth, rather than relying solely on force (Guriev and Treisman, 2022, 2019).

[2] Caplan et al. (2018) argues that the speed of disinformation spread is higher than content moderation. Chan et al. (2017); Nyhan and Reifler (2010); Ecker et al. (2022) study the impact of debunking and rebuttal and find limited effects.

Our method consists of two stages. First, we construct a model to detect accounts that are likely to spread disinformation, even before they do so, primarily using the position of the accounts within the network. Second, we use the information pertaining to the first few initiators of each pieces of news on social media to promptly identify disinformation before it becomes viral. Finally, we provide estimates of this approach's effectiveness in curtailing the spread of disinformation on social media platforms.

To validate our methodology, we apply it to a real-world scenario, the Woman, Life, Freedom protests in Iran that followed death of Mahsa Amini in September 2022.[3] This event triggered widespread demonstrations and a surge in social media activity, accompanied by a flood of disinformation through imposter accounts.[4] Using data from X (formerly Twitter), we demonstrate the effectiveness of our approach in this context.

We construct a comprehensive data set comprising all posts on platform X in Farsi, from September 16, 2019, to March 14, 2023. We augment this data with account characteristics, network-based and non-netwrok-based. We supplement our dataset with hand-collected instances of disinformation and true news events that occurred during this period. Furthermore, we include organic rebuttals to these disinformation events on platform X.

In the first stage of our approach, we devise an algorithm based on network and non-network account characteristics to categorize users that post in Farsi on X into three categories: ordinary, unsafe, and pro-regime. Ordinary accounts are those that generally do not engage in either pro-regime propaganda or disinformation; unsafe accounts actively spread disinformation on social media; and pro-regime accounts openly engage in spreading pro-government propaganda.

We utilize a hand-collected labeled dataset of ordinary, unsafe, and pro-regime accounts to train and test the model, a multinomial logit with elastic net regularization. It achieves 95% accuracy in account classification. Moreover, our results highlight that the network-based characteristics play an integral role in identifying accounts likely to spread disinformation, providing a strong foundation for our network-based method of combating disinformation.

The second stage aims to identify disinformation events on X as soon as they begin. We employ the first stage's categorization of the first few accounts that initiate each piece of news on X. If many of these initial accounts are classified as unsafe, we label that piece of news as "disinformation." Using data up to four months ahead of the disinformation date, our model identifies at least 85% of ex-post verified disinformation instances without

[3]The 22-year-old Iranian woman died in a Tehran hospital after her arrest by Iran's morality police for alleged hijab violations. Fury grows in Iran over woman who died after hijab arrest. Accessed 01/17/2024.

[4]Meta removes Iran-based fake accounts targeting Instagram users in Scotland. Accessed 01/17/2024.

mistakenly labeling any true news as disinformation. As our proposed approach relies solely on the category of the first few initiators of news events to identify disinformation, it provides a tangible opportunity to take preventive steps before disinformation goes viral, making it an effective mechanism to combat the spread of disinformation.

We are ultimately interested in quantifying the effectiveness of employing this method in restricting the spread of disinformation on social media platforms. To achieve this goal, we first estimate the causal impact of organic rebuttals by political activists on the flow of disinformation on X, during the same time period. We then use these estimates to quantify the impact of the adoption of network-based disinformation labeling by X on the extent of disinformation spread. Our estimates in Section 4 show that implementing our approach leads to a three-fold reduction in the number of posts related to disinformation campaigns. Furthermore, the maximum user engagement rate for disinformation is reduced by at least half, and its effective lifespan is cut by at least 50%, significantly limiting its potential impact.

A possible concern is that accounts that spread disinformation on social media platforms might attempt to modify their behavior to avoid detection. To alleviate this concern, we adjust the algorithm to rely exclusively on network-based characteristics that are less susceptible to manipulation. Our analysis, detailed in Section 5.1, shows that this non-manipulable model performs comparably to the baseline model in accurately classifying both disinformation and real news.

We also examine the value of data in determining the performance of the model in Section 5.2. We find that the size of our training set is considerably more important than the length of the training data in ensuring a high model performance.

1.1 Literature Review

Our paper contributes to the extensive body of literature on the economics of media. One strand of this literature considers media capture by governments and its consequences (Besley and Prat, 2006). A second strand studies the political economy of media censorship. Some papers focus on the government obstructing access to valuable information (Schedler, 2010; Shadmehr and Bernhardt, 2015), while others explore the effects of public demand for uncensored and non-ideological information (Gentzkow and Shapiro, 2006; Chen and Yang, 2019; Simonov and Rao, 2022), another strand studies the impact of change in technologies on news production (Cagé et al., 2020b; Angelucci et al., 2020).

We focus on a less explored intervention employed by authoritarian regimes to influence political outcomes: the deliberate spread of disinformation on social media platforms,

aimed at distorting waves of unrest. Gottfried and Shearer (2016) emphasize the significance of social media, providing evidence that approximately two-thirds of adults in the United States access their news through these platforms. Cagé et al. (2020a) show that even mainstream media are impacted by social media news. In their research, Allcott and Gentzkow (2017) delve into the theoretical and empirical aspects of fake news dissemination on social media prior to the 2016 election. Moreover, Thomas et al. (2012) and Stukal et al. (2017) present evidence highlighting the extensive use of false information, particularly on Russian Twitter.

Estimating the volume of misinformation circulating on social media between 2015 and 2018, Allcott et al. (2019) found that user interactions with false content increased steadily on Facebook and Twitter until the end of 2016. However, they also discovered a sharp decline in interactions with false content on Facebook since then, while interactions on Twitter continued to rise. Additionally, Bradshaw and Howard (2018) conducted an examination of organized social media manipulation campaigns in 29 countries worldwide, uncovering evidence of governments employing social media as a tactic for manipulation.

Given the abundance of evidence regarding the use of social media in manipulating public opinion, several researchers have explored methods to combat this issue, see Bak-Coleman et al. (2022). Some researchers have proposed real-time fact-checking and moderation of information. However, Vosoughi et al. (2018) show that false information tends to spread faster than true information. They investigate the differential diffusion of true and false news stories using a comprehensive dataset of fact-checked rumor cascades on Twitter spanning from its inception in 2006 to 2017. Due to the rapid spread of misinformation, real-time moderation appears futile, as disinformation often goes viral before being detected by content moderators. While ex-post rebuttals of disinformation have been extensively studied, their impact has been found to be limited Kunda (1990); Chan et al. (2017); Nyhan and Reifler (2010); Ecker et al. (2022); Kahan et al. (2017).

There is also a strand of theoretical literature on information diffusion, information aggregation, and belief formation. The seminal work of Crawford and Sobel (1982) studies strategic dissemination of information using a cheap talk model. Acemoglu et al. (2010) consider the tradeoff between information aggregation and propagation of misinformation on social media. Akbarpour et al. (2020) studies the optimal seeding strategy for information diffusion in networks. Wang et al. (2024) propose a model information disclosure in social media, and show how reputational concerns affect the communication of potentially false information. Related to our policy experiments, Budak et al. (2011) study theoretical approximation algorithms that can effectively limit the spread of misinformation on social

media.

The rest of the paper is organized as follows. Section 2 provides details of the data that we use for estimation. Section 3 describes our proposed network-based approach for prompt identification of disinformation and the baseline estimation results. Section 4 estimates the impact of labeling disinformation using our approach on spread of disinformation on the social media platform. Section 5 presents various robustness exercises. Lastly, Section 6 concludes.

2 Data

We use data from X (formerly Twitter) spanning the period from the inception of the "Woman, Life, Freedom" movement in Iran–triggered by Mahsa Amini's death on September 16, 2022–to the discontinuation of the X API v1 streaming service on March 14, 2023, to construct a novel dataset.[5] We use this dataset to devise an algorithm to detect disinformation on X and measure its effectiveness in containing the spread of disinformation.

Our dataset has two main components. The first component consists of all the X accounts who have more than 10% of their interactions in Farsi and have posted at least ten times after September 2022. This component includes these accounts' characteristics, posts, engagements, and their social network. The second component consists of 14 instances of disinformation, augmented by 1,374 organic rebuttals of these disinformations in 924 distinct threads of posts, as well as 10 instances of relevant true news that were spread on X during the time period of interest. We explain each component separately below.

Accounts, posts and social network In order to construct a comprehensive set of accounts active in Farsi X during this period, we combine the data from X v1 API and v2 API. The X v1 API gives us an archive of all Farsi-language posts made after September 16, 2019.[6] The X v2 API allows us to get a complete network construction of active accounts in our data by finding all follower-following links among them.

X v1 API stream allowed its users to collect a stream of all new posts filtered on a number of parameters, provided that the stream made up less than 1% of new posts. By

[5]See https://www.britannica.com/topic/Woman-Life-Freedom for more details about the "Woman, Life, Freedom" movement in Iran. Accessed 07/06/2024.

[6]The archive is hosted by Brandeis University. The data from X v1 API was originally collected by Leyla Hashemi and Steven Wilson and the early part of the data, September 19, 2019 - January 28, 2021, underlies the paper Hashemi et al. (2022). The streamer continued to collect data until the termination of the X API v1 streaming service on March 14, 2023. See Hashemi et al. (2022) for an overview of this dataset.

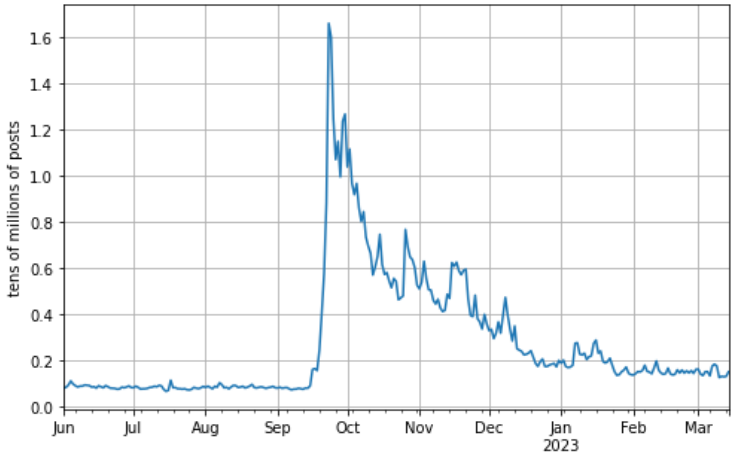


Figure 1: Daily volume of Farsi-language posts on X during 6/1/2022-3/14/2023

including a filter that only lets through posts written in Farsi and given that Farsi language posts are almost never more than 1% of new posts, the combination includes almost all Farsi language posts since September 16, 2019. Figure 1 depicts a substantial increase in activity in the Farsi language X after the start of the protests in Iran.

A post object contains detailed information about its content and its creator. Each post is identified by a unique post ID, includes text, timestamp and public metrics (such as the count of reposts, quote posts, replies, and likes), along with the creator's unique ID, username and public metrics (including the number of followers, followings, and posts), at the time of posting.

As posts are stored immediately upon creation, they report no subsequent engagements. However, posts that interact with another post (such as reposts, quote-posts, and replies) include a reference to the post they engage with. As such, by documenting nearly all Farsi posts after their creation, we can reconstruct a sequence of all subsequent engagements to every post. This allows us to map out the complete structure of Farsi-language X, including every reply thread and every chain of quote-posts and reposts.

Furthermore, by replacing each post's ID with that of its creator, we can trace the history of follower/following interactions between any two accounts on X and construct the social network among them.

The number of X accounts who have ever posted in Farsi is very large, with more than nine million accounts. However, most of these accounts have posted only a handful of times in Farsi.[7] To study accounts with a meaningful presence in the Farsi-speaking network of

[7]These are often non-Iranian users employing the popular "Woman, Life, Freedom" hashtags or sharing a friend's post. Additionally, the algorithm that determines the language of posts has errors and sometimes

	Total	Monthly average pre 09/2022	Monthly average post 09/2022
Full Sample			
Number of accounts	9,525,800	711,600	1,240,600
Number of posts sent	83,937,899	1,896,500	2,610,900
Number of reposts sent	639,337,800	9,637,000	48,734,300
Number of quote posts sent	57,919,800	1,345,300	1,581,500
Number of replies sent	377,199,600	8,264,700	13,278,400
Active Accounts			
Number of active accounts	1,767,350	614,000	1,016,300
Number of posts sent	62,212,685	1,351,200	2,261,600
Number of reposts sent	589,714,000	8,364,400	44,186,200
Number of quote posts sent	52,452,100	1,198,945	1,248,300
Number of replies sent	349,949,200	7,840,700	12,080,400

Notes: Active accounts are those with more than 10% of posts and engagements in Farsi and at least ten posts since September 2022 in Farsi.

Table 1: Aggregate and monthly statistics pre and post September 2022

accounts, we restrict our sample to accounts who post in Farsi often. We define an *active account* as accounts who have at least 10% of their posts in Farsi and have also posted at least ten times in Farsi since the protests began. As shown in Table 1, while focusing on active accounts reduces the number of accounts by a factor of 5, the number of interactions does not drop significantly. Therefore, restricting the data to this subset does not result in a significant loss of generality.

Disinformation and true news In order to test and train the model and measure its effectiveness in classifying disinformation on X and containing its spread, we need a sample of disinformation and true news instances.

We hand collect two sets of news spread on X during this time period. The first set consists of 14 ex-post verified disinformation campaigns that originated on X. These rumors are described in Table A.1 in Appendix A.1.[8] We then manually identify 1,374 organic rebuttals in 10 of the disinformation instances. These rebuttals are in the form of engagements with disinformation posts by activists to contest the validity of the disinformation posts and have happened on 924 independent threads of posts.[9] We augment our disinformation

misclassifies Arabic or Urdu as Farsi.

[8]Three independent journalists provided assistance, verifying that these campaigns were indeed disinformation campaigns, and traced their origin to X. See Section 5.3 for more details.

[9]We review all the posts associated with each of these 10 disinformation campaigns and mark all posts

sample with these rebuttals. The second set of news consists of 10 ex-post verified instances of relevant true news which happened during the same episode, described in Table A.2.

Using the above dataset, we collect and construct various characteristics for each account, as explained in Sections 2.2 and 2.3,[10] and use these characteristics to classify accounts in Section 3.1. The most important set of characteristics in our identification process is a set of network proximity to labeled accounts. In what follows, we first explain how we label accounts, and then we describe the construction of account characteristics.

2.1 Labeled Dataset

A "disinformation campaign" corresponds to a piece of news whose initiators are aware of its falsehood when they start spreading it on the social network. In our context, these false news were spread mainly to obfuscate what is happening during the protests and to undermine the opposition. Many of these disinformation campaigns originated on X and spread to other social media platforms, such as Instagram and Telegram. Section 3 provides details of our two-step approach to identify these disinformation campaigns. We first construct a model to identify Farsi-X accounts into three categories, and then use the category of accounts who initiate a piece of news to label the news as disinformation or not.

We label accounts in our dataset as one of the following three categories: "unsafe" accounts who actively participate in disseminating disinformation; "ordinary" accounts who do not; and "pro-regime" accounts who openly support the Islamic Republic of Iran and participate in its propaganda efforts.[11] One can further consider two groups of unsafe accounts. First, the "imposter" accounts who initiate the disinformation spread or spread it intentionally. In the context of "Woman, Life, Freedom" protests, these accounts initially pretend to be from an opposition group, posting pro-dissidence content and hashtags to build a network among the protesters. Subsequently, they start posting disinformation at the right time.[12] The second group consists of "naive" normal X accounts who engage in the spread of disinformation, albeit unintentionally. For the purpose of identifying disinformation news events, we do not need to distinguish between these two sets of accounts.

To execute and evaluate our methodology, it is necessary to begin with a collection of

that rebutted the initial disinformation. The reason we did not use the others was the lack of apparent rebuttal before the rumor stopped spreading.

[10] Table A.3 in the Appendix A provides more detail of the construction.

[11] These accounts publicly engage with propaganda of Islamic Republic but do not hide their allegiance and therefore are easier to identify by both the public and our algorithm as reported later on.

[12] Our analysis indicates that these rumors typically begin with a few accounts located in different parts of the network, all sharing a piece of fake news with almost identical phrasing, with slight variations in word choice.

labeled accounts of these three groups. The most challenging category is unsafe accounts. We only use imposter unsafe accounts to train our classifier in order to be conservative. We label the first 5% of the *initiators* of the verified disinformation campaigns that we have collected in our dataset as unsafe. As these accounts have created at least one instance of disinformation on X within our data, they are by definition unsafe. This procedure gives us a list of 476 unsafe accounts.

We next label an initial set of "pro-regime" accounts. In contrast to unsafe accounts, pro-regime accounts do not hide their true allegiance, and therefore it is easy to distinguish and label them. We include two sets of accounts here. First, we include various I.R.I. leaders and other accounts of popular pro-regime agents. Second, we choose random posts of the I.R.I leader and then randomly pick accounts who have liked these posts. We then manually check these accounts one by one to make sure that they are all pro-regime accounts. This procedure gives us a list of 470 pro-regime accounts.

An obstacle in labeling ordinary accounts for the case of Iran is that ordinary accounts often operate in anonymity to protect themselves and their associates from political prosecution, making it difficult to distinguish them from unsafe accounts.[13] Thus, we label a set of accounts as ordinary accounts from a diverse group of individuals, ranging from well-known opposition leaders and celebrities to our friends and family and their acquaintances whose identities can be attested. This procedure gives us a list of 489 ordinary accounts.

In summary, we have a total of 1,435 labeled accounts: 476 unsafe, 489 ordinary, and 470 pro-regime accounts. We divide this set into a training set containing 70% of labeled accounts from each category and a testing set with the remaining 30%.

2.2 Basic Characteristics

As a baseline, our classifier includes basic account features and activity statistics such as the number of followers and followings, follower-to-following ratio, account age, rate of posting by post type, and post composition by type. However, we can expect these measures to become less predictive as disinformants strategically change their behavior to impede detection.

In order to take advantage of the explosion of activity that took place on Farsi-X following the death of Mahsa Amini, we consider account features and activity before and after September 16 2023. This includes whether an account was created before or after the start

[13]There has been numerous cases of prosecution and even executions for online activities on X or other social media in Iran, see for example https://iranwire.com/en/politics/110844-young-iranian-woman-detained-for-46-days-over-tweet/. Accessed 06/21/2024.

of the protests, changes in account activity throughout the protests, and the interaction of the two.[14]

2.3 Network Characteristics

The key distinguishing feature of our algorithm is the use of network characteristics. These characteristics indicate different proximity measures for each account to the accounts in the training set. We construct two sets of these metrics, one set for relationship with known unsafe accounts and one for relationship with known pro-regime accounts. The intuition behind these characteristics is that unsafe (pro-regime) accounts tend to follow and echo other accounts that are unsafe (pro-regime). In addition, this connectivity is a crucial factor for the success of a disinformation campaign. For a post to go viral and spread through the network, it must be widely shared and liked by numerous other accounts. In what follows, we explain the construction of these network proximity measures.

For any two accounts, u and v, we consider four types of relationships which we call "proximity scores:" 1) Following: u follows v, 2) Follower: u is followed by v, 3) Repost: u has reposted v, 4) Reposted: u has been reposted by v. We construct eight proximity scores for each account, four for each of the above engagements with unsafe accounts, and four for engagements with pro-regime accounts.

As an example, consider the construction of the proximity score for *unsafe following*. Start with the initialization step and give all the unsafe accounts in the training set a score of 1 and all other accounts a score of 0. Next, move to the iterative step. In this step, first choose an account randomly among the ones with the highest score. Note that in this example, it will certainly be an unsafe account in the training set in the first round. Find all accounts that this account is *following* them and add one to their score. That is, in this example the "connected" unsafe accounts in the training set will get a score of 2, and the rest of the "connected" accounts will get a score of 1 in the first round. Repeat the iterative score until a terminal condition is satisfied.

As the score construction algorithm is random, we simulate it ten times and set the average of the scores to be the final score for each account. The set of final scores constitutes the corresponding proximity scores. Appendix A.3 provides details of the algorithm for construction of the proximity score for *unsafe following*. The other seven proximity scores are defined similarly.

[14] We constructed this dataset using input from multiple activists and journalists.

3 Detecting Disinformation on Social Media: A Network-based Approach

The network spread of disinformation is similar to the spread of infectious disease: It starts exponentially, reaches a peak, and dies out rapidly. As such, it is crucial to flag disinformation promptly after its origination and before the spread becomes pervasive.

Previous studies have highlighted real-time content moderation and ex-post efforts to eliminate audience biases as essential strategies to contain the spread of fake news, but they have pressing limitations. Real-time fact-checking or content moderation is time-consuming, thus allowing disinformation to go viral before it can be addressed. Furthermore, ex-post debunking has shown limited impact in debiasing the public.[15] Motivated by these deficiencies, we propose an alternative approach to restrict the supply of disinformation—a network-based approach for detecting disinformation to enable ex-ante content moderation.

Our method has two steps. First, we employ a network-based algorithm to predict accounts likely to engage in spreading disinformation, even before they do so, and assign a category to them. Second using the category of their initiators, we label the news spread on social media as disinformation, shortly after their initiation. Section 3.1 describes our methodology for determining the account categories of social media, and Section 3.2 provides the details of our news labeling procedure.

3.1 Determination of Account Category

This section outlines our baseline methodology for identifying account categories and subsequently presents the estimation results.

Estimation methodology. We calculate a triplet propensity score for each account in our data as the probability of belonging to the ordinary, unsafe, or pro-regime group. For each account with attributes $y \in Y$ we estimate $(p_o(y), p_u(y), p_p(y))$ where p_o is the probability that this account is an ordinary account, p_u is the probability of being an unsafe account, and p_p is the probability of being a pro-regime account, and $p_o + p_u + p_p = 1$. In the remainder of the paper, we will refer to p_u and p_p as *disinformation score* and *pro-regime score*, respectively.

Our estimation methodology is analogous to propensity score matching, a widely adopted

[15] Caplan et al. (2018) argues that the speed of disinformation spread is higher than content moderation. Chan et al. (2017); Nyhan and Reifler (2010); Ecker et al. (2022) study the impact of debunking and rebuttal and find limited if any impact.

method to estimate treatment effects (Heckman et al., 1997; Smith and Todd, 2001; Becker and Ichino, 2002; Dehejia and Wahba, 2002; Hirano et al., 2003). We use a multinomial logit to estimate the propensity scores. This model assumes that the error terms in the classification come from an extreme-value distribution. Given a set of explanatory variables $y \in Y$, the propensity score of being an ordinary account, i.e., the likelihood of an account being ordinary, is given by

$$p_o(y) = \frac{exp(\beta_o y)}{exp(\beta_o y) + exp(\beta_u y) + exp(\beta_p y}.$$

Where $\beta_o, \beta_u, \beta_p$ are the coefficients corresponding to the ordinary, unsafe, and pro-regime groups, respectively. The likelihood of an account being classified as unsafe or pro-regime is described analogously. As with other choice models, we can only identify these coefficients up to a constant; therefore, we normalize the coefficients of ordinary accounts, β_o, to zero and report the other two sets of coefficients.

To estimate the logistic regression, we use seventy percent of the labeled accounts and the explanatory variables described in Section 2.[16] To avoid overfitting, we apply a regularized fit. This fit is an elastic net with equal weights on L1 and L2 penalties. The resulting set of nonzero regressors is then passed into logistic regression.

The estimated Logistic regression provides us with three propensity scores (p_o, p_u, p_p) for each account. We categorize each account into the group with the highest propensity score. For instance, if an account's scores are represented as $p = (0.5, 0.2, 0.3)$, it would be categorized as an ordinary account. The results and accuracy rate of this method are reported in the next section.

Estimation results. Table 2 reports our baseline estimation results. Recall that these coefficients should be interpreted relative to ordinary accounts, for which the coefficients are normalized to 0. Also, note that the reported variables in the table are those selected by the elastic net. Several key findings warrant additional emphasis. First, all of the network proximity measures defined in Section A.3 are selected by the elastic net which underscores their importance in identifying account categories. Next, when examining the coefficients for unsafe accounts, two variables within the unsafe network proximity measures are positive and highly significant: *unsafe follower* and *unsafe reposted*. In contrast, the other two variables, *unsafe following* and *unsafe reposts*, are not significant. This is a notable observation as it implies that unsafe accounts are not easily differentiated from ordinary accounts based on their own following or reposting behavior, as they attempt to mimic the

[16] Details of the explanatory variables is provided in Appendix A.2.

	Unsafe		Pro-regime	
	coef	std err	coef	std err
log(Unsafe Following Score)	-0.72	0.46	-3.10	0.54
log(Unsafe Followers Score)	4.65	0.44	-0.46	0.53
log(Unsafe Reposts Score)	0.15	0.38	-1.79	0.69
log(Unsafe Reposted Score)	3.45	0.38	-0.41	0.85
log(pro-regime Following Score)	-2.39	0.72	3.62	0.88
log(pro-regime Followers Score)	1.02	0.61	4.22	0.72
log(pro-regime Reposts Score)	-0.32	1.70	0.25	0.26
log(pro-regime Reposted Score)	2.31	0.49	4.01	0.36
Eigen Followers Centrality	0.38	4.51	0.75	0.49
Followers to Following Ratio	0.06	109.82	0.12	1.91
Account Age	-1.56	0.55	-0.59	0.49
Is New Account	1.30	0.29	0.93	0.28
% Change Following	-1.34	0.27	-0.70	0.24
Replies Sent Rate	-0.11	0.71	-0.11	0.74
Proportion Reposts	-1.35	0.32	-0.24	0.34
Proportion Quote Posts	-2.75	0.96	-1.48	1.10
Proportion Replies	-2.36	0.36	-1.07	0.35
Followers to Following Near 1	0.40	0.47	0.38	0.22
New Account x Quote Posts Sent Rate	-1.24	0.72	-0.65	2.23
New Account x Proportion Reposts	-1.23	0.38	-0.77	0.46
New Account x Proportion Quote Posts	-0.57	1.98	-0.06	1.36
pro-regime Hashtag Score	0.86	1.08	0.65	0.66
No. Observations:	1,004			
Log-Likelihood:	-0.11			
Pseudo R-squ.:	0.94			

Notes: This table shows the multinomial logistic regression coefficients for the baseline model, regularized with an elastic net with equal L1 and L2 penalties. Factors with point estimates of zero were pushed to zero by the elastic net. The coefficients for ordinary category is normalized to zero.

Table 2: Baseline model

patterns of ordinary accounts by following and reposting ordinary accounts. However, they are unable to compel ordinary accounts to follow them or share their content, resulting in a higher number of similar unsafe accounts following and reposting their content which enables us to identify them.

Furthermore, several non-network characteristics are also significant. In particular, unsafe accounts tend to be newer, which is likely caused by X policy of shutting down accounts once they realize that an account is suspicious.[17] Additionally, unsafe accounts' engagements involve a larger proportion of original posts as opposed to reposting or replying to other accounts' posts, when compared to ordinary accounts.

[17]Although there is a disinformation policy in place in X, our analysis indicates that this policy only addresses a small portion of these accounts as the majority are still active.

Category	Precision	Sensitivity
Ordinary	92.6%	93.9%
Unsafe	93.6%	92.3%
pro-regime	99.3%	99.3%

Notes: Total accuracy: 95.13%

Table 3: Precision and sensitivity for the baseline model

Let us now examine the characteristics of the pro-regime accounts compared to the ordinary accounts, the second block of Table 2. The coefficients of network proximity to pro-regime accounts are all positive and highly statistically significant, confirming that these accounts tend to be very connected and echo each other's message. Additionally, the coefficients of network proximity to unsafe accounts for these accounts are all negative and *unsafe following* and *unsafe reposts* are significant. The latter finding illustrates that pro-regime try to distance themselves from unsafe accounts.

We utilize the remaining 30 percent of labeled accounts which were excluded from the training set as test data to measure the performance of the model. Table 3 reports the precision and sensitivity of the model classification for the three categories of accounts, as well as its total accuracy.[18,19] The total accuracy of the model is reassuringly high, 95.13%. The precision and sensitivity rates are also high for all three groups. Particularly, for pro-regime accounts, both precision and sensitivity are nearly 100%, with a single false positive and a single false negative, ensuring that we can accurately identify almost all such accounts. However, differentiating unsafe and ordinary accounts is more challenging as unsafe accounts try to mimic ordinary accounts actively to avoid detection. Table 3 indicates that we missclassify between 6% and 7% of ordinary and unsafe accounts. There is a tradeoff between precision of unsafe and ordinary accounts. Depending on the policy one wishes to implement, it may be necessary to prioritize reducing false negatives in one group over the other. We explore this tradeoff further in Section 5.4.

Next, we use the multinomial logit model to categorize all of the accounts our sample into ordinary, unsafe, and pro-regime groups by assigning them to the category with the highest propensity score. The results are reported in Table 4. We classify about 16% of active Farsi accounts as unsafe accounts, i.e., accounts that participate in disseminating disinformation, intentionally or unintentionally. We further classify 8% of accounts as pro-regime accounts.

[18]For each account category, precision is calculated as $\frac{tp}{tp+fp}$, and sensitivity (also known as recall) is calculated as $\frac{tp}{tp+fn}$, where tp represents true positives, fp represents false positives, and fn represents false negatives.Total accuracy is defined as the percentage of correctly classified instances.

[19]Appendix Table B.6 reports the confusion matrix for this model.

Account Category	Count
Ordinary	1,339,454
Unsafe	285,549
Pro-Regime	142,347

Table 4: Account classification

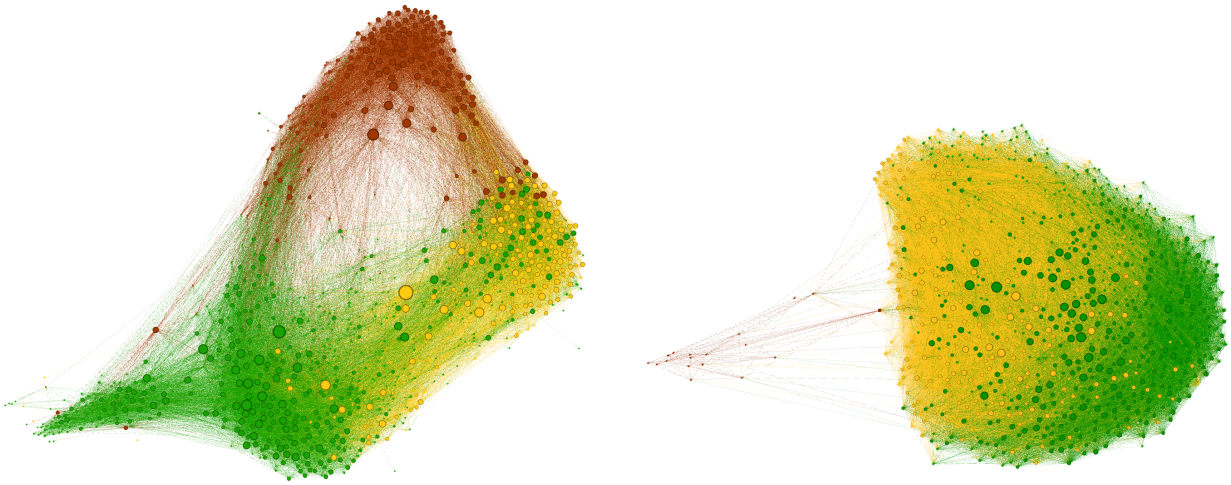
Our account classification provides interesting insights into the network structure of the social media platform. Since the number of active accounts on X is prohibitively high for meaningful visualization, we limit our analysis to the networks of the 1,000 most active accounts, displayed in Figure 2. Figure 2a illustrates the follower-following network among the 1,000 accounts with the highest number of followers, while Figure 2b depicts the tweet-reposting activity network of the 1,000 accounts with the highest number of reposts. The size of each node is proportional to the account's centrality in the network, and its color is based on the classification of accounts: unsafe accounts are shown in yellow, pro-regime accounts in red, and ordinary accounts in green.

There are a few noteworthy observations. First, as illustrated in Figure 2a, accounts within each category are highly interconnected. However, unsafe accounts have managed to infiltrate ordinary account networks. This integrated frontier is where disinformation permeates ordinary accounts. In contrast, most ordinary accounts steer clear of pro-regime accounts. Moreover, comparing the two figures, it is evident that unsafe accounts are significantly more active in posting and reposting content, as they have a greater presence in the repost network of the top 1,000 accounts compared to the most followed accounts. On the other hand, pro-regime accounts fail to get much engagement from either ordinary or unsafe accounts.

3.2 Disinformation Labeling Based on Initiators' Category

In Section 3.1 we explain how our algorithm uses existing data, mainly from the network structure of the social media platform, to determine accounts that actively engage in the spread of disinformation already or are likely to do so in the future, even if they have not yet. In this section, we leverage this information to identify the disinformation itself as quickly as possible to contain its spread. We call our proposed method the network-based disinformation labeling approach.

Our algorithm indicates two consistent patterns across different pieces of news disseminated on X. First, each instance of disinformation is originated predominantly by unsafe



(a) Follower-following network of most followed accounts

(b) Repost-reposted network of most reposted accounts

Figure 2: Network of the 1,000 most active accounts

Notes: Yellow nodes represent unsafe accounts who are likely to spread disinformation, red nodes represent pro-regime accounts who are likely to spread propaganda, and green nodes represent ordinary accounts who are less likely to engage with either activity.

accounts. Second, although the unsafe accounts do participate in spread of true news as well, they are less involved in its origination. We use these two observation to discern disinformation from real news by identifying the composition of their initiators on social media. Informed by these two insights, we posit that if k out of the first n initiators of a news on the platform are unsafe accounts, then it is highly likely that the piece of news is disinformation.

Despite achieving high total accuracy, our model does not perfectly identify the labeled test accounts. For instance, Table 3 reports that our algorithm misclassifies some unsafe accounts as ordinary and vice versa. As our labeling relies on the category of the initiators of the news, we have to be careful about the possible spillover of the account misclassification into disinformation labeling. Furthermore, to identify disinformation, our approach relies on identification of account categories based on past data, as opposed to ex-post fact-checking. It follows that the performance of the algorithm depends on the training data, as any other classifier. However, for the approach to be feasible, it is important that its classification performance is reasonable without requiring continuous updating of the training data.

These imply that it is important to carefully choose the parameters (k, n) in order to achieve two goals. First and foremost, we want to avoid missing disinformation or incorrectly flagging news as disinformation, due to account misclassification. Second, we

would like to minimize the sensitivity of model performance to the training (and length of testing) data.

We choose $n = 10$.[20] In order to choose k optimally, we train the baseline model with the first 6 instances of the first ex-post verified disinformation in our data, taken place between begging of September 2022 and mid-October 2022, using different time intervals of training data. We then test the trained classifier with the remaining 8 ex-post verified instances of disinformation, taken place between mid-October 2022 to end of February 2023 (Table A.1) and 10 ex-post verified instances of true news which happened during the Woman, Life, Freedom episode of unrest (Table A.2). Table B.9 in Appendix 3.2 reports the detailed results of this exercise. Informed by those results, we propose the following labeling rule:

Definition 1 (**Network-Based Disinformation Labeling**). *A piece of news is labeled as disinformation if and only if the baseline model classifies 7 out of its first 10 initiators as unsafe accounts.*

Figure 3 illustrates the performance of network-based disinformation labeling in correctly detecting disinformation events. The solid blue line represents the percentage of true news events labeled as disinformation, which remains at zero regardless of the length of the training data. This minimal false-positive error rate ensures that our disinformation labeling approach does not impede the flow of true news on social media. Conversely, the dashed red line indicates the percentage of disinformation events labeled as such. The model performs well in correctly detecting disinformation, although there is a non-zero false-negative error rate. As expected, the dashed red line modestly increases with the length of the training data period, ultimately reaching 100% correct detection of disinformation by the midpoint of our sample time interval.

The distinct advantage of our network-based disinformation labeling approach is that it enables swift discovery of disinformation on online platform, through two distinct channels. First, we propose detecting a disinformation event after participation of only ten accounts. Due to the exponential spread of news on social media, this is crucial for effective disruption of disinformation. Second, we are able to correctly detect disinformation events using account data last updated four months prior. Specifically, using account data up to the end of October 2022, which only includes the six earliest disinformation campaigns in our sample, we successfully identify disinformation events as of the end of February 2023 as illustrated in Figure 3.[21] As such, adopting this approach significantly reduces the need to

[20] We have also tried $n = 5, 15$. $n = 10$ gives the most consistent predictions.

[21] While expanding the training set and data can enhance the performance of the algorithm, continuous updates are not necessary to maintain its effectiveness.

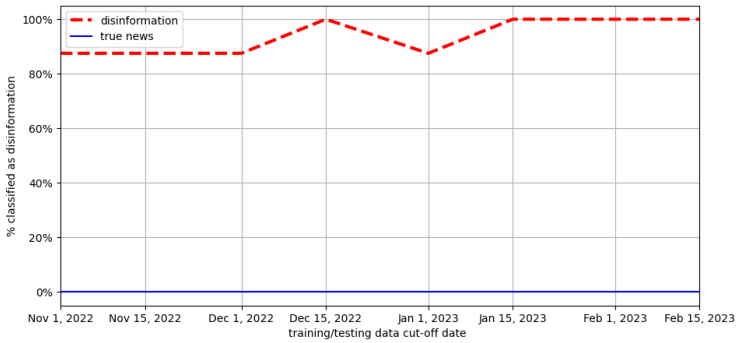


Figure 3: Labeling disinformation and true news as disinformation

Notes: This figure illustrates the accuracy of labeling eight instances of disinformation (last 8 rows of Table A.1) and ten true news events (Table A.2) for different lengths of training data period, as a function of duration of data used for training. If the algorithm classifies at least seven of the first 10 accounts who initiate the corresponding thread as unsafe, we label the news as disinformation.

for the platform to engage in extensive content moderation ex-post.[22] Section A.4 in the Appendix provides suggestive guidelines for implementing this approach by social media platforms.

4 Restricting the Spread of Disinformation

The US Supreme Court ruling on June 26, 2024, allows the White House and federal agencies to continue urging social media platforms to take down disinformation without violating the First Amendment. This ruling underscores the importance of prompt identification of disinformation to be able to prevent proliferation of disinformation among social network accounts.

As such, we would like to estimate the effectiveness of our network-based disinformation labeling approach in mitigating the spread of disinformation on social media. To do so, we first measure the effectiveness of flagging a piece of news as disinformation on its social media spread. We then use this estimates to quantify the impact of our network-based labeling approach to restrict the spread of disinformation. We find that this approach reduces the number of posts by a factor of three, and decreases the maximum user engagement and the lifetime of a rumor by at least a factor of two.

[22] After facing a class action lawsuit from content moderation workers, Facebook began hiring external contractors, with Accenture being the largest, reportedly receiving over $500 million in 2021. https://www.nytimes.com/2021/08/31/technology/facebook-accenture-content-moderation.html, accessed 08/10/2024.

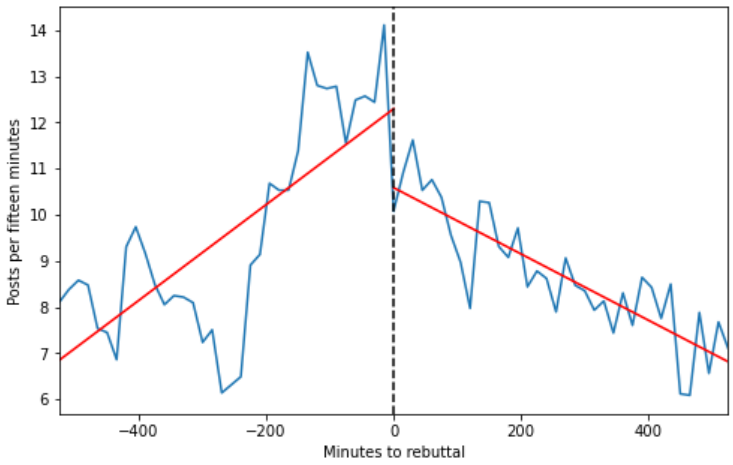


Figure 4: Effect of rebuttal on disinformation spread

Notes: This figure exhibits the average number of posts per fifteen minutes across all threads in which a rebuttal has occurred over time. Time zero is the time of the first rebuttal of the thread. The best fit line is in red.

4.1 Impact of Decentralized Rebuttals on Disinformation Spread

During the Woman, Life, Freedom movement in Iran, the most common interruption to the spread of disinformation on X was through rebuttals of disinformation posts by political activists, in a fully organic, decentralized fashion. Recall that we have manually identified 1,374 such rebuttals in 10 of the 14 ex-post verified disinformation campaigns in our sample.

Let an *original post* be one which is not a comment within another post, a repost, or a quote-repost. Let a *thread* denote a tree of posts, comments, reposts, and quote reposts whose root is an original post. Each of the disinformation campaigns we study consists of many threads of different lengths. Of all the rebuttals, 924 of them occur on different threads. When multiple rebuttals occur on a single thread, we restrict attention to the first rebuttal.

Figure 4 illustrates the average number of posts per fifteen minutes across all threads where a rebuttal has occurred. Time zero represents when the first rebuttal happens, and positive (negative) numbers are time after (before) the rebuttal. There is a clear discontinuity at time zero when the first rebuttal happens. More importantly, the rebuttals disrupt the exponential spread of the rumor and revert the slope of the number of posts to negative.

In order to model the impact of rebuttals on the spread of disinformation, we need to make an assumption about who can see each rebuttal, as we do not have information on impressions. We assume that the rebuttals in each thread are observed only by accounts

who participate in that particular thread and not the rest of the disinformation campaign.[23]

We then conduct a difference-in-differences analysis to determine the effect of rebuttals. We model the number of posts within each thread during each 15-minute time interval as a Poisson process. As the number of posts changes even in the absence of rebuttals, we assume that the process is mean-varying. We estimate the mean using various time controls, as well as other fixed effects which depend on the history, and also include disinformation campaign fixed effects.

We assume that the number of posts in thread i of a news event j at time t follows a generalized Poisson linear model, $Y_{i,j,t} \sim Poisson(\mu_{i,j,t})$, where $\mu_{i,j,t}$ represents the mean of the Poisson process. For each thread i of the news event j, we denote the time of the first rebuttal as $\tau_{i,j}$. We estimate β_1, the effect of a rebuttal that takes place at time $\tau_{i,j}$, on $Y_{i,j,t}$, the number of posts at time $t \geq \tau_{i,j}$, using the following regression discontinuity in time model:

$$\mu_{i,j,t} = \alpha + \beta_1 \mathbb{1}_{t \geq \tau_{i,j}} + \beta_2 Y_{i,j,t-1} + \beta_3 Y_{i,j,t-1} \times \mathbb{1}_{t \geq \tau_{i,j}} + \text{Fixed-Effects}_{i,j,t}. \tag{1}$$

We include three sets of fixed effects. The first set is disinformation-specific fixed effects, which controls for the varying levels of engagement with different disinformation campaigns. The second set involves time-specific fixed effects, such as the day of the week and the hour of the day. The third set pertains to the rumor's history, such as the count of different types of posts in the campaign up to time t.

Table 5 reports the results of the regression in Equation (1) with alternative sets of fixed effects. The constant term represents the average number of posts in the absence of any rebuttals. Alternatively, the coefficient of rebuttal shows how much this average decreases after rebuttal occurs. Both of these estimates are statistically significant with apposite signs, as expected. Furthermore, comparing them points to a substantial decline in the spread of disinformation campaign after a rebuttal. For instance, in the last column that includes all fixed effects, a rebuttal leads to an approximately 80% decline in the number of posts. This result is consistent with recent research that shows that warning labels for social media posts can considerably reduce the spread of misinformation (Martel and Rand, 2023).

[23] This assumption has a couple of implications. First, it implies that threads are independent of one another. As such, we ignore the spillover that rebuttals have on the rest of the campaign and can lead to earlier termination of the spread of false news. On the other hand, it implies that when a rebuttal appears, it is seen by all participants of that thread going forward. Neither of these simplifying assumptions is precise. However, we believe that the aggregate effect of this simplifying assumption likely underestimates the impact of rebuttals.

constant	4.78	4.69	1.84	5.28	2.69
	(2.0E-2)	(8.0E-3)	(0.04)	(3.0E-3)	(0.07)
rebuttal	-2.08	-1.98	-1.97	-2.35	-2.15
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
lagged posts	7.0E-4	8.0E-4	9.0E-4	8.0E-4	9.0E-4
	(5.5E-7)	(8.3E-7)	(1.1E-6)	(1.2E-6)	(1.9E-6)
lagged posts × rebuttal	0.01	0.01	6.7E-3	6.7E-3	6.6E-3
	(7.9E-5)	(8.15E-5)	(8.9E-5)	(8.6E-5)	(8.9E-5)
time elapsed	-1.1E-7	-1.0E-7	-3.1E-7	-1.7E-7	-2.7E-7
	(5.2E-10)	(5.2E-10)	(1.7E-9)	(6.3E-10)	(1.9E-9)
time elapsed × rebuttal	-2.4E-6	-2.7E-6	-2.6E-6	-6.8E-7	-1.3 E-6
	(1.1E-7)	(1.2E-7)	(1.3E-7)	(9.8E-8)	(1.1E-7)
time fixed-effects	X	✓	X	X	✓
history fixed-effects	X	X	✓	X	✓
campaign fixed-effects	X	X	X	✓	✓
N	4,851	4,851	4,851	4,851	4,851

Notes: In this regression, rebuttal is a dummy variable equal to 1 if the time period is after a rebuttal occurred.

Table 5: Results of regression discontinuity in time

4.2 Effectiveness of Network-Based Disinformation Labeling

In this section, we estimate the effect of our network-based disinformation labeling, introduced in Definition 1, on the spread of disinformation if it is adopted by the social media administration in a centralized manner. We use the estimated impact of decentralized rebuttals, reported in the last column of Table 5.

We perform two distinct sets of simulations for each thread of each disinformation event, according to Equation (1). The first set, the "baseline" simulations, follows the history of realized disinformation events by setting the rebuttal indicator of a rebutted thread to the time its corresponding thread was rebutted.[24] As such, these simulations replicate the average statistics of the realized disinformation events.[25] The second set, the "network-based labeling" simulations, measures the impact of our network-based labeling approach on the spread of disinformation, if it is adopted by the social media platform in a decentralized fashion and is used to label news events as disinformation early in their lifespan.

In summary, we simulate each disinformation event thread-by-thread, assuming that the number of posts in a thread at time t follows a Poisson distribution with mean given by

[24]Some of the disinformation campaigns never experience a rebuttal.

[25]This approach ensures a more robust comparison set, as we can verify that results are not driven by differences between the simulations and the actual data.

	Realized	Baseline Simulation	Network-based Labeling
Total # of Posts	9,668	11,204	3,238
Maximum Rate of Posts	629	552	342
Time to $<$ 42 Posts	168 hours	104 hours	26 hours
Time to $<$ 28 Posts	170 hours	125 hours	55 hours

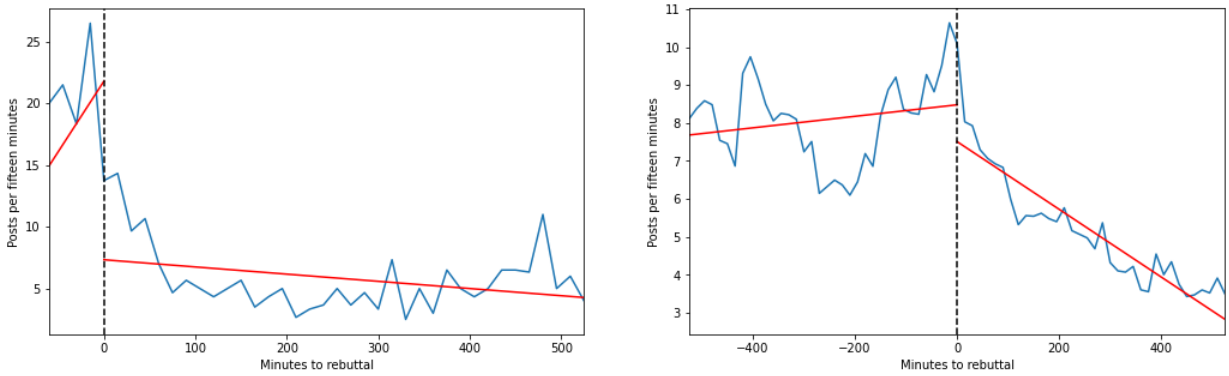
Notes: This table reports average measures of spread of disinformation on platform X for the 10 realized disinformation events that have been rebutted, as well as their corresponding baseline and network-based labeling simulations. We report three types of diffusion statistics: 1) number of posts in a disinformation event, 2) the maximum number of posts per hour, 3) the time until it falls and stays below 42 and 28 posts per hour (these threshold are the average number of posts at the 90th and 95th percentile across all the disinformation events). The three columns are values from the data, the corresponding simulations using Equation (1), and a counterfactual where the disinformation was detected and labeled (by our network-based approach) using the estimates for the impact of rebuttal reported in Table 5.

Table 6: Impact of network-based labeling on disinformation spread

Equation (1), using estimates reported in the final column of Table 5. Each thread begins at the time indicated in the data but evolves based on the corresponding simulation. For the "baseline" simulations, we use the time of the first rebuttal within each thread in the data as $\tau_{i,j}$. For the "network-based labeling" simulations, we assume that all existing threads of the disinformation event are rebutted simultaneously at the time of the 10^{th} original post of the news event in the data, which is when our approach labels a piece of disinformation as such. The simulation method is explained in detail in Appendix A.5.

We measure the extent of spread of disinformation using three statistics. The number of posts in the disinformation campaign, the maximum account engagement rate, and the duration of the disinformation campaign. Table 6 reports these statistics, averaged over the disinformation events in our sample, for the realized events and the two sets of simulations.

We observe that, on average, the number of posts related to the disinformation campaign decreases significantly, by a factor of three. Additionally, the maximum user engagement rate, measured as the maximum number of posts per hour on a given campaign, decreases substantially by approximately half. To estimate the effective lifetime of a disinformation event, we calculate the number of posts per hour at the 90th and 95th percentiles of all instances of disinformation. We then determine the duration required for a disinformation event to reach at most that many posts per hour using both the actual data and the two sets of simulations. This analysis demonstrates that the effective lifespan of disinformation has notably shortened, by half or a quarter, depending on the measure used. Collectively, these findings indicate that our algorithm significantly reduces engagement with disinformation and mitigates its spread.



(a) Rebuttal at most 1 hour after the first tweet of the thread

(b) Rebuttal at least 4 hours after the first tweet of the thread

Figure 5: Effect of early versus late rebuttals on disinformation spread

Notes: This figure exhibits the average number of posts per fifteen minutes across threads in which a rebuttal has occurred over time, grouped by time of the first rebuttal relative to start of the thread, early and late. Time-zero is the time of the first rebuttal of the thread. The best fit line is in red.

One key advantage of our method is its ability to quickly label disinformation before it spreads widely and becomes viral. While organic rebuttals may occur at various stages throughout the spread of false news, either early or late, we hypothesize that early detection is crucial for curtailing the spread of disinformation, due to the exponential nature of news dissemination on social platforms.

To explore this hypothesis empirically, we analyzed the impact of rebuttals on disinformation spread as a function of their timing relative to the original post that started the corresponding thread. We examine two subsets of threads: those rebutted within the first hour of the original post—early, and those rebutted after four hours—late. Figure 5 illustrates our findings.

Comparing the early rebuttal panel 5a with the late rebuttal panel Figure 5b exhibits a substantial impact for early rebuttals. As expected, the average impact of rebuttals shown in Figure 4 falls between these two extremes. We conclude that the estimates reported in Table 6 likely represent a lower bound on the benefits of the adoption of this approach by social media platforms to contain the spread of disinformation.

A potential concern is that disinformation spreaders might alter their behavior to evade detection if a platform adopts the network-based disinformation labeling policy. The estimates presented in Table 6 are based on a crucial assumption: to successfully spread disinformation, unsafe accounts must maintain high connectivity within the social network while avoiding detection by ordinary users. This necessitates not only strong connections among themselves but also strategic positioning within the broader network through in-

teractions with ordinary accounts. As depicted in Figure 2, this involves engaging in the spread of true news and establishing follower and following relationships with ordinary accounts. Given these requirements, the network-based characteristics are not susceptible to rapid manipulation. Section 5.1 demonstrates that a non-manipulable classifier that relies solely on network-based characteristics performs nearly as well as the baseline model in labeling disinformation. This finding suggests that the estimates in Table 6 provide reasonable approximations of the approach's impact in the short term, even when considering potential manipulation behaviors by disinformation spreaders.

So far, we have focused on the benefits of adopting the network-based disinformation labeling approach in restricting the spread of disinformation on social media. At the same time, we believe this approach can potentially reduce the cost of detecting disinformation for platforms substantially through process automation and reduction of manual content moderation labor costs. Our algorithm involves two labor-intensive steps: first, verifying a number of disinformation events using news content to initialize the process, and second, creating a labeled dataset for training and testing the algorithm. The rest of the algorithm can be fully automated. While these steps need to be repeated intermittently to ensure the labeling algorithm's performance, the rest of the algorithm needs minimal if any updates. The automation of the majority of the process is likely to provide a significant cost-saving opportunity for social media platforms.

5 Robustness

In this section, we conduct several exercises to ensure that our results are robust to various model specifications and the data used for training.

5.1 Manipulating Account Characteristics

In the (dis)information war, disinformants behave as normal accounts so that other users believe their posts as true news, while in reality they spread disinformation. In other words, unsafe accounts mimic ordinary accounts to blend in, which in turn makes their detection challenging. Therefore, a concern with using the output of an account classifier for punitive measures is that it might encourage users to alter their behavior further to manipulate the scores, which could decrease the model's accuracy.

In order to mitigate possible manipulation from unsafe accounts, we restrict attention to characteristics that are hard to manipulate while maintaining being highly connected and blended in with ordinary accounts. We posit that network characteristics are harder to ma-

	Unsafe		Pro-regime	
	coef	std err	coef	std err
log(Unsafe Following Score)	-1.74	0.44	-4.01	0.45
log(Unsafe Followers Score)	5.96	0.21	-0.19	0.38
log(Unsafe Reposts Score)	-0.23	0.36	-2.08	0.58
log(Unsafe Reposted Score)	2.75	0.34	-0.83	0.78
log(pro-regime Following Score)	-3.88	0.65	3.37	0.83
log(pro-regime Followers Score)	0.89	0.57	3.99	0.60
log(pro-regime Reposts Score)	-0.14	1.59	0.40	0.24
log(pro-regime Reposted Score)	2.32	0.44	3.94	0.33
Degree Followers Centrality	-0.91	0.97	35.44	36.35
Eigen Followers Centrality	1.08	9.30	1070.05	1065.89
No. Observations:	1,004			
Log-Likelihood:	-0.18			
Pseudo R-squ.:	0.89			

Notes: This table shows the multinomial logistic regression coefficients for the non-manipulable model that uses network characteristics only, regularized with an elastic net with equal L1 and L2 penalties. Factors with point estimates of zero were pushed to zero by the elastic net. The coefficients for ordinary category is normalized to zero.

Table 7: Non-manipulable model

nipulate as they rely on the structure of the whole network which encompasses the ordinary accounts. As such, collective action by unsafe accounts cannot easily manipulate them. For example, while unsafe accounts can follow and share posts from ordinary accounts, they cannot compel ordinary accounts to follow them back or share their posts. Additionally, the network metrics for each account are influenced by the actions of accounts that are several connections away, thereby reducing the likelihood of successful manipulation.

We revise the baseline algorithm in Section 3.1 by exclusively using network characteristics. Table 7 presents the updated estimation results.[26] The coefficients are generally aligned with those from the baseline model which included a broader set of variables. However as reported in Table B.10, due to the restriction to network characteristics, model's accuracy declines to 93.7% from a baseline of 95.1%. This decline is primarily driven by the lower accuracy rate in identifying ordinary and unsafe accounts. Precision for ordinary accounts declines to 90.0% from 92.6%, and precision for unsafe accounts declines to 91.5% from 93.6%.[27]

Despite the decrease in accuracy in identifying account categories when restricting atten-

[26]There are possibly other hard-to-manipulate variables from the baseline model. To err on the side of caution, we opted to use solely network-based characteristics.

[27]Table B.13 in Appendix 5.1 reports the estimation results when using only *non-network* variables, which implies a significant drop in model performance, reported in Table B.14. Total accuracy drops to 73.3%. This underscores the critical role of network variables.

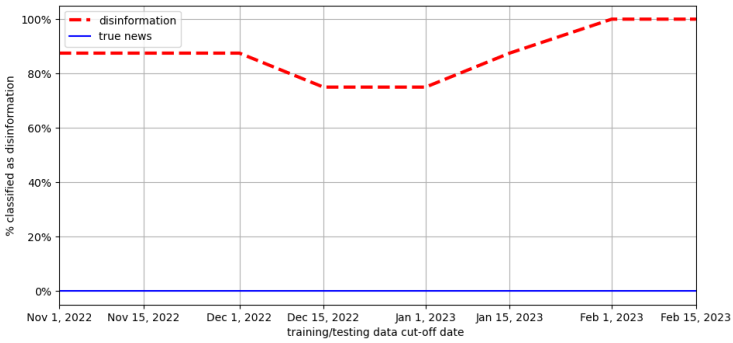


Figure 6: Labeling disinformation and true news as disinformation: Non-manipulable model

Notes: This figure illustrates the accuracy of labeling eight instances of disinformation and ten true news events for different sizes of training data, as a function of duration of data used for training when only network based variables are used. If the algorithm classifies at least seven of the first 10 accounts who initiate the corresponding thread as unsafe using only network variables, we label the news as disinformation.

tion to non-manipulable network characteristics, the impact on identifying disinformation campaigns is minimal, as illustrated in Figure 6. There is a slight reduction in the probability of identifying disinformation campaigns, while still no instances of real news are misidentified as disinformation.

The performance of the non-manipulable model in discerning disinformation from true news aligns with the theoretical insights from studies on optimal signals in the presence of manipulation, as discussed in Frankel and Kartik (2019); Perez-Richet and Skreta (2022); Saeedi and Shourideh (2023). These studies suggest employing an opaque scoring scheme that makes manipulation harder. When we use account scores to identify disinformation campaigns instead of disclosing account scores themselves, it becomes difficult for unsafe accounts to determine how to evade disinformation flags. Firstly, they are unaware of which accounts under their control have been flagged. Secondly, they lack precise information on the reasons for the flagging, making it harder to evade it in the future. This reinforces the algorithm's resilience against manipulation.

A potential long-run strategy for disinformation spreaders could involve creating entirely new accounts and building new relationships. Positioning these new accounts within the social network of ordinary users is a time-consuming process. Moreover, to evade detection by the network-based algorithm, these accounts would need to establish connections within clusters of other newly created unsafe accounts, avoiding links to previously identified unsafe accounts. These evolving tactics present an opportunity to enhance our detection algorithm by incorporating time-based characteristics. For instance, we could consider the percentage of an account's followers that are new, or the proportion of its first ten followers created

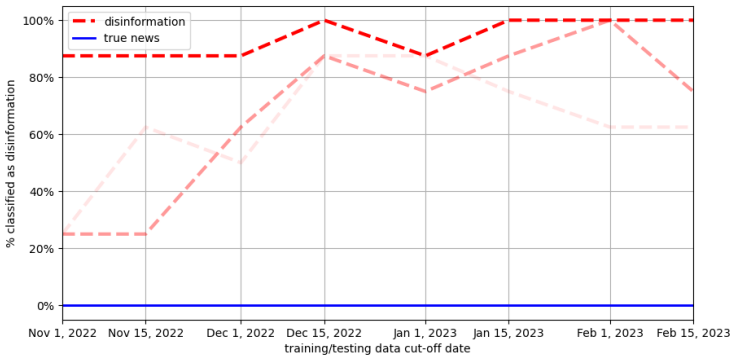


Figure 7: Labeling disinformation and true news as disinformation: Training data

Notes: This figure illustrates the accuracy of labeling eight instances of disinformation and ten true news events for different sizes of training data, as a function of the end date of data used for training. If the algorithm classifies at least seven of the first 10 users who initiate the corresponding thread as unsafe, we label the news as disinformation. The blue (red) lines correspond to disinformation (real news). Darker lines represent classifiers with a larger training set, measured by the number of disinformation campaigns used for training (1, 3 or 6).

within k-days of the account's own creation. While implementing such enhancements would be challenging, they could significantly mitigate potential long-run manipulation efforts by disinformation spreaders.

5.2 Value of Training Data

Our model relies on a classifier for detecting disinformation, where the training data plays a crucial role. There are two dimensions through which the training data can be improved: 1) increasing the number of disinformation campaigns included in the training data, hence enlarging the training set, and 2) extending the duration of data used for training while keeping the training set constant. The former dimension allows the model to identify unsefe accounts based on their network interactions with a broader set of verified unsafe accounts, while the latter dimension implies that the model considers longer-term interactions of the same set of accounts.

We have already shown that when the training dataset includes six disinformation campaigns, the model accuracy starts high even with a limited duration of the training data. As such, although increasing the length of the data used for training results in higher accuracy, the improvement is marginal, as illustrated in Figure 3.

Figure 7 explores both dimensions of improvement in training data in a more general way. In particular, it compares the accuracy of the baseline model trained with 1, 3, or 6 disinformation campaigns, while the end of the training period varies from mid-September

2022 to March 2023.[28] Similar to Figure 3, blue curves correspond to the probability that a true news is mistakenly classified as disinformation, while the red curves are the probability of correct detection of disinformation.

A significant finding in Figure 7 is that utilizing a single disinformation campaign and data up to mid-September 2022 to train the model is sufficient to discern that all true news are not disinformation. However, increasing the number of disinformation events in the training sample significantly improves the accuracy of detecting disinformation, particularly with a limited duration of training data.

As such, while increasing the duration of training data enhances the algorithm's accuracy, the impact of enlarging the training set is notably more pronounced. We believe that this is due to the fact that unsafe accounts put a lot of effort to act as ordinary accounts and keep distance from some other unsafe accounts, to avoid all being detected. Thus, by including sufficiently many unsafe accounts in the training set, the model is able to identify new clusters of unsafe accounts who have not participated in the first few disinformation campaigns and thus identify new disinformation more successfully.

5.3 Expert Validation

To validate the results of our model, we conducted an external verification by hiring three independent journalists who are active on X. We provided them with a random list of accounts, including both accounts from our labeled set and other accounts identified solely based on our algorithm. The journalists were not informed which accounts belonged to the labeled set. We asked them to assign probabilities to each account, indicating the likelihood that an account falls into one of three categories: ordinary, unsafe, or pro-regime. For example, for a specific account, a journalist might assess an 80% probability of being ordinary, a 20% probability of being unsafe, and a 0% probability of being pro-regime. They could also assign a 100% probability to a single category if they were certain.

We first consider the propensity scores provided by the journalists for the set of labeled accounts they had received.[29] Several notable observations emerge. First, the journalists often expressed uncertainty in their classifications; in 65% of the cases, they did not assign an account to a category with 100% probability. Second, the scores assigned by different journalists varied significantly, especially for ordinary and unsafe categories.[30] Third, our

[28] With fewer disinformation events in the training set, one can consider an earlier final date for availability of training data.

[29] These accounts are ones for which we are certain of their category.

[30] The standard deviations for ordinary and unsafe scores provided by journalists were 0.26 and 0.24 respectively, while the standard deviation for pro-regime scores was 0.03.

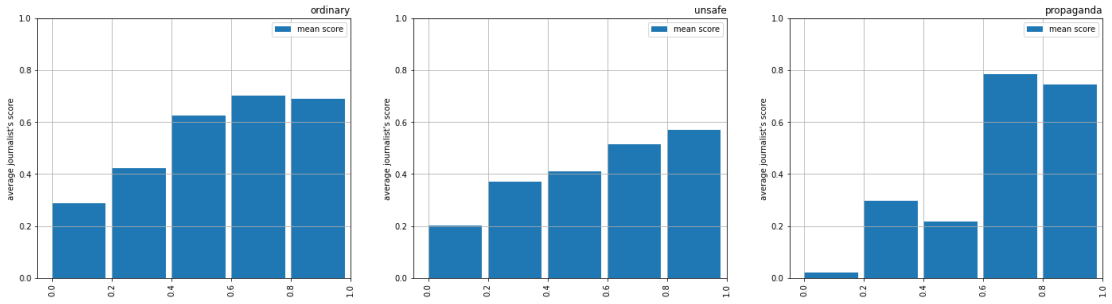


Figure 8: Journalists' average propensity score vs. algorithm's propensity score
Notes: Each figure illustrates the propensity score assigned to accounts, averaged over the three journalists, for quantiles of the algorithm-generated propensity scores, for one category of accounts.

algorithm demonstrated higher accuracy than the most accurate journalist, achieving 93% accuracy compared to 87%. These observations underscore the value of incorporating a model capable of tracing network relationships which can achieve a more efficient and accurate outcome than that of experts.

Next, we compare the journalists' propensity scores with those of our algorithm for accounts not included in the labeled set. We calculate a weighted average score for each account by assigning a weight to each journalist based on their accuracy rate for labeled accounts.[31] Figure 8 compares their weighted propensity scores to the algorithm's propensity scores. This figure presents the average scores for all accounts within each quantile for the algorithm propensity scores. A positive correlation is observed for both ordinary and unsafe accounts, as shown in the first two panels. Accounts that our algorithm identified as highly likely to be ordinary (or unsafe) also received higher probabilities of being ordinary (or unsafe) from the journalists. Additionally, the journalists' predictions for pro-regime accounts closely align with that of the algorithm's, which is expected given that we defined pro-regime accounts as those overtly supporting the regime, which are thus easier to identify.

Finally, Figure 9 depicts the accuracy of the baseline model in categorizing disinformation and true news using the ordinary account provided by the independent journalists to estimate the logistic regression. The figure clearly illustrates that the performance of the model is robust to the training data.

[31] The weight for journalist i is $\text{accuracy}_i/(\sum_j \text{accuracy}_j)$.

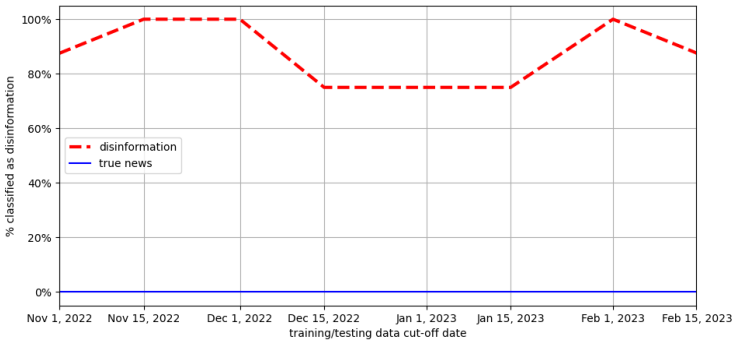


Figure 9: Labeling disinformation and true news as disinformation: Estimation using ordinary accounts provided by independent journalists

Notes: This figure illustrates the accuracy of labeling eight instances of disinformation and ten true news events for different sizes of training data and training using only ordinary accounts provided to us by independent journalists. If the algorithm classifies at least seven of the first 10 accounts who initiate the corresponding thread as unsafe using only network variables, we label the news as disinformation.

5.4 Precision and Sensitivity Tradeoff

In this section, we consider the precision and sensitivity of the model in labeling accounts, which is the crucial input to identifying disinformation campaigns. Similarly to any other classifier, our model exhibits a tradeoff between precision and sensitivity of labeling. However, in certain circumstances, one might be specifically concerned about the performance of the model for one group of accounts. For instance, one might seek to maximize the number of unsafe accounts that are correctly labeled as unsafe, or alternatively, one might aim to guarantee that every ordinary account is correctly labeled as ordinary. Either of these goals can be achieved through a slight adjustment of the algorithm, which we describe next.

Given the high precision and sensitivity in classifying pro-regime accounts, we exclude them from the subsequent analysis. We will continue to classify accounts with the highest pro-regime score into the pro-regime group as before. Our focus will be on accounts identified by our algorithm as either unsafe or ordinary. For each account, we calculate $p_u - p_o$, which represents the difference between their unsafe and ordinary propensity scores. Figure 10 illustrates the distribution of $p_u - p_o$ for the unsafe and ordinary test accounts labeled by the model. The left panel depicts the distribution of correctly labeled account while the right panel depicts that of the incorrectly labeled accounts. The two panels clearly show that for the accounts that are incorrectly labeled by the model, the propensity score to be an unsafe versus ordinary are a lot more similar.

In order to control the precision and sensitivity of account classification directly, we

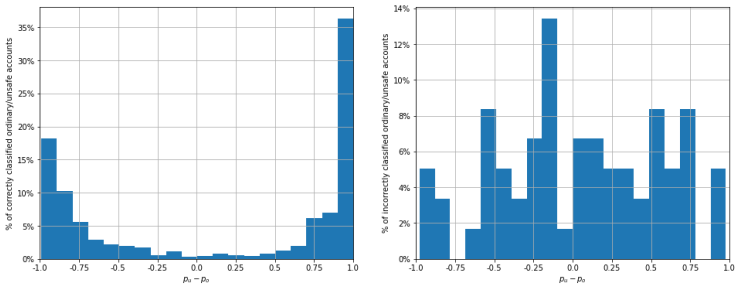


Figure 10: Histogram of differences between ordinary and unsafe propensity score

Notes: The left histogram shows the distribution of $p_u - p_o$ for accounts that are correctly labeled by the baseline model as ordinary or unsafe. The right histogram shows the distribution for accounts which are misclassified.

introduce a "propensity score threshold," ϵ, and consider its comparison with $p_u - p_o$. By changing the propensity score threshold one can achieve a specific precision or sensitivity. If $p_u - p_o < \epsilon$, we reclassify this account as ordinary. By increasing ϵ we label fewer accounts as unsafe. In other words, relabeling accounts using a higher propensity score threshold increases sensitivity for ordinary accounts and precision for unsafe accounts by as it is more stringent about calling an account unsafe. Note that so far we identify an account as the category with the highest propensity score, i.e., $\epsilon = 0$.

Table 8 reports the precision and sensitivity of labeling ordinary and unsafe accounts as we change the threshold ϵ form 0.05 to 0.3. Consistent with the contrast between the two histograms in Figure 10, by increasing ϵ we reduce how often ordinary account are misclasified as unsafe, albeit at the expense of increasing the misclassification of unsafe accounts as ordinary.

6 Conclusion

In this paper we introduce "(dis)information wars," the intentional spread of disinformation on social media platforms, often by oppressive governments or other political actors, in order to counter the growing use of these platforms as vehicles of dissidence across the world.

We then propose a novel method to impede the disinformation war—the network-based labeling approach to disinformation detection. Our methodology relies on identifying disinformation events on social media using the characteristics of their first few initiators, to contain the spread of disinformation before it goes viral.

We take advantage of data from X during the recent wave of social unrest in Iran, the "Woman, Life, Freedom" movement, to estimate the performance of our proposed approach

	Baseline	0.05	0.1	0.15	0.2	0.25	0.3
Ordinary Precision	92.6%	92.6%	92.0%	91.4%	90.8%	90.8%	89.7%
Ordinary Sensitivity	93.9%	93.9%	93.9%	93.9%	93.9%	93.9%	95.2%
Unsafe Precision	93.6%	93.6%	93.6%	93.6%	93.6%	93.6%	94.8%
Unsafe Sensitivity	92.3%	92.3%	91.6%	90.9%	90.2%	90.2%	90.2%

Notes: Effect of reclassifying the accounts classified as unsafe as ordinary by the baseline model using $p_u - p_o < \epsilon$ instead of $p_u - p_o > 0$, where $\epsilon = 0.05, 0.1, 0.15, 0.2, 0.25, 0.3$

Table 8: Precision and sensitivity for the baseline model using the $p_u - p_o < \epsilon$ criteria

in identifying disinformation campaigns on X during this episode. We find that using data only up to four months ahead of the disinformation date, our model is able to identify at least 85% of ex-post verified disinformation instance without misclassifying any true news as disinformation.

To quantify the impact of network-based labeling approach on containing the disinformation spread, we first causally estimate the effect of organic, decentralized rebuttals of disinformation on X, during the same episode. We then employ these estimates to measure a lower bound on the impact of the centralized implementation of our labeling approach by the platform and find that it leads to a three-fold reduction in the number of posts and reduces the maximum user engagement rate and the effective lifespan of disinformation by at least a factor of two.

These results suggest that unlike live moderation and fact checking or ex-post debunking, an ex-ante network-based disinformation detection approach can significantly mitigate the spread of disinformation on social media. We believe that the substantial impact of this method despite its high tractability makes it a beneficial approach for a wide range of scenarios where the spread of disinformation is a problem, thereby bolstering our ability to counteract the negative impact of disinformation proliferation.

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Appendix

A X Data: Supplemental Information

A.1 Ex-post Verified Disinformation and True News

Tables A.1 and A.2 outline the 14 pieces of disinformation and the 10 true news, all ex-post verified, used in our analysis.

rumor	start date	description
Health of Khamenei	September 1, 2022	Prior to and through the start of the Women, Life, Freedom protests, rumors of Khamenei's declining health and death began being circulated.
Account balance of Reza Ostadi	September 10, 2022	Alleged screenshots of Reza Ostadi's bank account balances began circulating showing an exhorbitant balance.
Komle's arrival in Kurdistan	September 19, 2022	Word began to spread which indicated that separatist forces were beginning to amass in Kurdistan in historic opposition to the IRI.
Rape of Nika Shakarmi	October 4, 2022	Disappeared protestor Nika Shakarmi, whose death security guards had a suspected role in, was rumored to have also been raped before her death.
Murder of Asra Panahi	October 12, 2022	Asra Panahi died after being hospitalized following a clash with security forces at her school. The role of security forces in her death was quickly called into question.
Murder of Pardis Javid	October 14, 2022	Reported death of a Kurdish student who was allegedly kidnapped by security forces during a protest just before her death.
Murder of Hana Duzduzani	October 14, 2022	One of several false names reported to have died in conjunction with the real death of Asra Panahi, whose death was falsely reported to have been by suicide.
Assault of Armita Abbasi	October 23, 2022	Rumor began to circulate that the protestor Armita Abbasi had been hospitalized due to multiple sexual assault following her arrest.
Venezuelan political refuge	November 1, 2022	Rumor began to spread of high-level officials seeking political asylum in Venezuela over pressure from the protest movement.
Massacre at Saadat-Abad Square	November 20, 2022	Reports of indiscriminate open fire by IRI security forces at civilians at Saadat-Abad Square after a soccer match.
Arrest and torture of Hasan Firoozi	December 8, 2022	Fictitious political prisoner who had a video of his circulate in which he pleads with IRI officials to let him see his newborn daughter before his scheduled execution.
Death of Judge Salavati	January 5, 2023	False reports of Judge Salavati's death began to circulate at the beginning of the year.
Assault of Sara Shirazi	February 21, 2023	An azreshi woman was reported to have assaulted a school girl in Isfahan for improperly wearing her religious garb.
Murder of Fatemeh Rezaee	February 26, 2023	Rumor began to spread that a protester in Qom had died due to overexposure to poisonous chemicals used by riot police. Qom officials had allegedly threatened anyone who knew about the death.

Table A.1: List of the collected ex-post verified disinformation

news event	start date	description
Arrest of Majid Tavakoli	September 22, 2022	The political activist Majid Tavakoli was arrested in the early days of the Women, Life, Freedom protest movement.
Execution of Mohsen Shekari	December 8, 2022	Mohsen Shekari was executed by hanging having been convicted of the assault of a paramilitary militia member.
Death of Rostam Ghasemi	December 8, 2022	Rostam Ghasem, Iran's former Minister of Urban Development, died as a result of chronic illness.
Release of Majid Tavakoli	December 19, 2022	The political activist Majid Tavakoli was released after having been detained for three months following his participation in the early Woman, Life, Freedom protest movement.
Torture and Death of Mahdi Zare	January 2, 2023	The protestor Mahdi Zare fell into a coma and died following his release from custody. His death is thought to have resulted from torture while he was in custody.
Arrest of Navab Ebrahimi	January 5, 2023	The social media influencer Navab Ebrahimi was arrested without pretense but is thought to be related to the taunting of general Qassem Suleimani.
Trial of Yalda Moeeri	January 6, 2023	The photojournalist Yalda Moeeri underwent sentencing for spreading anti-IRI propaganda.
Ahmad-Reza Radan Appointment	January 7, 2023	The general Ahmad-Reza Radan was appointed police chief likely in response to the ongoing protests.
Execution of Mohammad Mahdi Karami	January 7, 2023	Mohammad Mahdi Karami was executed by hanging having been convicted for the murder of a paramilitary militia member.
Black Reward Hack of Imam Sadegh University	January 20, 2023	A group of hackers hacked into the network of Imam Sadeq University and threatened to release sensitive documents and information.

Table A.2: List of collected ex-post verified true news events

A.2 Account Characteristics

account characteristic	description
log(Unsafe Following Measure)	log of unsafe following measure (how ingrained an account's followings are with imposter accounts)
log(Unsafe Followers Measure)	log of unsafe followers measure (how ingrained an account's followers are to imposter accounts)
log(Unsafe Retweets Measure)	log of unsafe retweets measure (how ingrained an account's retweets are to posts made by imposter accounts)
log(Unsafe Retweeted Measure)	log of unsafe retweeted measure (how ingrained an account's retweeted posts are to those retweeted by imposter accounts)
log(pro-regime Following Measure)	log of pro-regime following measure (how ingrained an account's followings are with pro-regime accounts)
log(pro-regime Followers Measure)	log of pro-regime followers measure (how ingrained an account's followers are to pro-regime accounts)
log(pro-regime Retweets Measure)	log of pro-regime retweets measure (how ingrained an account's retweets are to posts made by pro-regime accounts)
log(pro-regime Retweeted Measure)	log of pro-regime retweeted measure (how ingrained an account's retweeted posts are to those retweeted by pro-regime accounts)
Degree Followers Centrality	account's degree centrality in follower-following network (number of edges to or from an account)
Eigen Followers Centrality	account's eigenvector centrality in follower-following network (centrality weighted by an account's connection to highly-centered nodes)
Betweenness Followers Centrality	account's betweenness centrality in follower-following network (centrality measured by an account's presence in the shortest paths between all other accounts)
Followers to Following Ratio	ratio of an accounts number of followers to followings
Account Age (days)	days since account's creation
Is New Account	an indicator as to whether an account was created after the start of the protests on September 16, 2022
% Change Followers	percent change in an account's number of followers since the start of the protests
% Change Following	percent change in an account's number of followings since the start of the protests
New Followers Rate	the rate at which an account has gained followers since the start of the protests
New Following Rate	the rate at which an account has followed accounts since the start of the protests
New Retweets Sent	the number of retweets an account has sent since the start of the protests
New Retweets Received	the number of time an account has been retweeted since the start of the protests
New Quote Tweets Sent	the number of quote tweets an account has sent since the start of the protests
New Quote Tweets Received	the number of time an account has been quote tweeted since the start of the protests
New Replies Tweets Sent	the number of replies an account has sent since the start of the protests
New Replies Tweets Received	the number of time an account has been replied to since the start of the protests
New Tweets Sent	the number of tweets an account has posted since the start of the protests
Tweet Rate	the rate at which an account tweets since its creation
Retweets Sent Rate	the rate at which an account retweets since its creation
Retweets Received Rate	the rate at which an account is retweeted since its creation
Quote Tweets Sent Rate	the rate at which an account quote tweets since its creation
Quote Tweets Received Rate	the rate at which an account is quote tweeted since its creation
Replies Sent Rate	the rate at which an account replies since its creation
Replies Received Rate	the rate at which an account is replied to since its creation
Proportion Retweets	the proportion of an account's total activity which is retweets
Proportion Quote Tweets	the proportion of an account's total activity which is quote tweeting
Proportion Replies	the proportion of an account's total activity which is replying to content
Followers to Following Near 1	an indicator as to whether an account has as many followers as they do followings $\pm 5\%$
New Account x Followers Rate	followers rate interacted with an account being new
New Account x Retweets Sent Rate	retweets sent rate interacted with an account being new
New Account x Retweets Received Rate	retweets received rate interacted with an account being new
New Account x Quote Tweets Sent Rate	quote tweets sent rate interacted with an account being new
New Account x Quote Tweets Received Rate	quote tweets received rate interacted with an account being new
New Account x Replies Sent Rate	replies sent rate interacted with an account being new
New Account x Replies Received Rate	replies received rate interacted with an account being new
New Account x Proportion Retweets	proportion of retweets interacted with an account being new
New Account x Proportion Quote Tweets	proportion of quote tweets rate interacted with an account being new
New Account x Proportion Replies	proportion of replies rate interacted with an account being new
pro-regime Hashtag Measure	a measure of how often an account uses hashtags which are also used by propagandists

Table A.3: Description of account characteristics included in the classifier

	All		Ordinary		Unsafe		Pro-regime	
	mean	stdev	mean	stdev	mean	stdev	mean	stdev
log(Unsafe Following Measure)	3.40	2.60	3.45	2.33	5.13	2.20	1.15	1.42
log(Unsafe Followers Measure)	3.25	2.70	1.53	1.55	5.77	2.25	2.09	1.74
log(Unsafe Reposts Measure)	3.58	3.25	3.78	3.06	5.66	2.77	0.70	1.36
log(Unsafe Reposted Measure)	3.23	3.22	2.29	2.18	6.39	2.43	0.32	0.68
log(Pro-regime Following Measure)	2.53	3.00	1.37	1.38	0.37	1.02	6.68	1.65
log(Pro-regime Followers Measure)	2.52	3.40	0.38	0.86	0.71	1.43	7.37	1.86
log(Pro-regime Reposts Measure)	1.95	2.93	0.64	1.07	0.19	0.56	5.76	2.75
log(Pro-regime Reposted Measure)	2.46	2.97	0.40	0.79	1.36	1.69	6.33	2.15
Degree Followers Centrality	1.35E-04	4.28E-04	1.65E-04	5.59E-04	6.47E-05	2.14E-04	1.90E-04	4.42E-04
Eigen Followers Centrality	1.41E-03	4.02E-03	2.44E-04	5.70E-04	2.21E-04	6.32E-04	4.31E-03	6.59E-03
Betweenness Followers Centrality	8.40E-05	1.62E-03	2.04E-04	2.77E-03	1.06E-05	6.90E-05	3.41E-05	1.37E-04
Followers to Following Ratio	761.44	9,964.05	96.02	703.59	251.36	3,334.70	2,204.43	18,092.18
Account Age (days)	943.27	482.93	1,190.02	401.85	709.60	460.62	947.74	452.31
Is New Account	0.25	0.43	0.07	0.25	0.46	0.50	0.20	0.40
% Change Followers	10.31	73.30	10.62	98.49	10.72	50.87	9.41	61.75
% Change Following	-0.36	0.48	-0.12	0.32	-0.61	0.49	-0.34	0.48
New Followers Rate	11.93	42.97	15.29	52.46	5.90	26.13	15.62	46.83
New Following Rate	0.55	1.66	0.43	1.11	0.29	1.20	1.01	2.45
New Reposts Sent	2,350.82	5,500.13	984.53	1,822.08	3,760.69	7,104.38	2,177.96	5,649.98
New Reposts Received	41,869.67	266,603.60	56,726.90	326,954.56	52,774.94	302,666.62	10,268.69	36,164.38
New Quote Posts Sent	422.39	4,735.54	319.60	490.23	753.68	7,782.55	121.97	240.60
New Quote Posts Received	2,481.56	16,389.50	4,393.53	26,494.51	1,667.71	7,345.73	1,244.30	4,680.45
New Replies Posts Sent	1,332.72	2,335.05	1,827.87	2,664.59	1,028.85	2,006.24	1,131.10	2,214.05
New Replies Posts Received	5,606.32	18,666.75	6,024.32	13,600.28	3,588.03	14,865.52	7,684.34	26,434.71
New Posts Sent	4,506.81	8,627.65	3,490.20	4,112.87	6,160.72	11,950.01	3,606.30	7,115.84
Post Rate	8.66	15.13	6.60	7.77	12.25	20.99	6.53	11.60
Reposts Sent Rate	4.57	11.68	1.47	3.39	8.15	16.84	3.68	8.35
Reposts Received Rate	49.21	337.62	51.73	314.31	68.16	460.61	22.02	79.61
Quote Posts Sent Rate	0.61	3.42	0.57	0.83	0.93	5.55	0.25	0.50
Quote Posts Received Rate	3.30	18.89	4.90	27.99	2.57	13.66	2.33	8.02
Replies Sent Rate	2.63	4.64	3.67	5.21	2.07	4.16	2.10	4.31
Replies Received Rate	8.01	23.29	8.79	15.57	5.14	20.41	10.75	32.35
Proportion Reposts	0.40	0.32	0.25	0.24	0.52	0.33	0.41	0.31
Proportion Quote Posts	0.06	0.07	0.09	0.06	0.05	0.08	0.04	0.06
Proportion Replies	0.35	0.27	0.46	0.24	0.22	0.21	0.40	0.29
Followers to Following Near 1	0.03	0.18	0.03	0.17	0.01	0.11	0.07	0.25
New Account x Followers Rate	0.69	8.76	0.22	2.59	1.47	14.17	0.25	1.17
New Account x Reposts Sent Rate	2.11	10.17	0.28	2.80	5.07	15.62	0.51	4.57
New Account x Reposts Received Rate	4.16	80.75	0.49	3.78	10.56	132.83	0.37	5.42
New Account x Quote Posts Sent Rate	0.14	0.68	0.06	0.45	0.31	0.98	0.03	0.29
New Account x Quote Posts Received Rate	0.31	6.37	0.05	0.45	0.77	10.47	0.03	0.41
New Account x Replies Sent Rate	0.39	2.16	0.15	0.96	0.75	3.03	0.20	1.77
New Account x Replies Received Rate	0.42	3.74	0.21	1.30	0.79	5.60	0.19	2.52
New Account x Proportion Reposts	0.13	0.29	0.04	0.16	0.27	0.37	0.07	0.22
New Account x Proportion Quote Posts	0.01	0.04	0.01	0.03	0.02	0.04	0.01	0.05
New Account x Proportion Replies	0.06	0.18	0.02	0.10	0.08	0.15	0.10	0.25
Pro-regime Hashtag Measure	0.10	0.08	0.10	0.07	0.09	0.06	1.13	0.09

Notes: Table A.3 in the Appendix provide descriptions of each characteristic. Statistics are reported for all the labeled accounts and each category of labeled account separately.

Table A.4: Statistics of account characteristics across different account categories

A.3 Construction of Network Measures Algorithm

In this section, we describe the algorithm used to define four network "proximity measures." We construct two sets of these measures, one set for proximity to known unsafe accounts and one for proximity to known pro-regime accounts.

We create four graphs in which each node represents an account, and the edges represent one of four binary relationships between any two accounts. Two accounts denoted as u and v, are connected in each graph if the corresponding condition is met:

1. Account u currently follows account v;
2. Account u is currently being followed by account v;
3. Account u has reposted account v; or
4. Account u has been reposted by account v.

For simplicity, we will refer to these relationships as follows: "following," "followers," "reposts," and "reposted," respectively.

We define our disinformation proximity measurement algorithm as follows. Given a random set of known unsafe and pro-regime accounts, at $t = 0$, we initiate our set of disinformation proximity measures on relationship-R (either following, followers, reposts, or reposted) by assigning a score of one to known unsafe accounts and zero to all other accounts. This scoring, L_t^R, maps accounts to their disinformation proximity measure based on relationship-R at iteration-t of the algorithm. Define $U_{t=0}$ as an empty set of exhausted accounts and select the natural number constant-k as the exit threshold. At each iteration t, we loop through the following steps:

1. Randomly choose an account, $u \in \text{argmax}_v\{L_t^R(v)\}$ (the set of accounts with the highest proximity measure at time t). If $u \in U_t$, go to $t + 1$.
2. Get the set of accounts who share the relationship-R with u, R_u. These are all the accounts who share an edge with account-u in the graph defined on relationship-R.
3. Define L_{t+1}^R by starting with L_t^R and increment the measure of each account in R_u by one if they are already in the domain of L_t^R, or otherwise add them to the domain of L_t^R with a measure of one.
4. $U_{t+1} = U_t + u$.

The algorithm terminates after T-iterations when $\|L_t^R\| = \|L_{t+k}^R\|$. The domain of the disinformation proximity measure map has not changed after k-iterations. Account-u's final disinformation proximity measure on relationship-R is $L_T^R(u)$.

A.4 Implementation by Social Media Platforms

Implementing this approach has two stages:

1. Algorithm for classifying accounts
2. Labeling news events based on account classification

Stage I: Construction of the account classification algorithm

1. Classification design
    - Decide on the groups for account classification
        - For disinformation detection, the base groups are unsafe and ordinary[32]
        - Possibly augment the model with further groups of accounts who exhibit distinct behavior from the base groups and can thus contaminate the estimation process if not separately considered.
          In this study: pro-regime accounts
    - Define the characteristics of each group
2. Create a labeled dataset of platform accounts
    - For unsafe accounts: Trace verified disinformation events to their initiators
    - For ordinary accounts: Use verified public figures, independent journalists, seek advice from field experts
3. Construct the network-based characteristics
    - Construct network proximity measures using steps in Appendix A.3
4. Augment with non-network characteristics
    - Identify and collect relevant non-network characteristics specific to the social media platform

[32]This method can be extended to other contexts where adversarial users create social network connections and exhibit herding behavior, such as identity theft purposes and other similar malicious behavior.

- Refer to the list of characteristics used in this study (Table A.3)

5. Train and test the logistic classifier
    - Split the labeled dataset: 70% for training, 30% for testing
    - Train the (bi)multinomial logistic regression using both network and non-network characteristics
        - Apply regularization (e.g., elastic net) to avoid overfitting
        - Include only characteristics with non-zero estimated coefficients
    - Test the model using the remaining 30% of the labeled accounts and make adjustments if needed
6. Classify all accounts
    - Apply the trained model to classify all accounts active on the platform into the defined groups

Stage II: Disinformation Labeling

1. Define the labeling rule
    - Condition L: If m out of the first n accounts originating a news piece are classified as unsafe, label it as disinformation
    - Set parameters m and n
        - Optimize using a set of verified disinformation and true news events to achieve the desired false positive and false negative rates
        - In this study: $m = 7$, $n = 10$
2. Implement the disinformation labeling
    - Monitor new news events on the platform
    - Identify the first n accounts sharing each news event
    - Use these accounts' classification to decide if condition L is satisfied
    - If so, label all the previous and subsequent posts related to this news as disinformation

To ensure that the algorithm stays up-to-the-date, these steps should be followed:

1. Periodic update and maintenance
    - Regularly update network and non-network characteristics of all accounts
    - Retrain the model periodically with fresh data to maintain accuracy
    - Add new accounts into the training set
2. Performance monitoring
    - Continuously evaluate the model's performance on verified disinformation and true news events
    - Adjust parameters (m, n) if necessary based on the desired false positive and false negative rates

A.5 Rebuttal Simulations: Baseline and Disinformation Labeling

This section details our simulation methodology for estimating the impact of disinformation labeling. To establish a robust comparison, we also simulate the baseline model using the regression results of Section 4.1.

Initialization: Time and threads:

- Divide time into 15-minute intervals.
- Let t_0^j denote the time of the first post of disinformation event j.
- Partition each disinformation event j into threads i, where threads are sets of posts with a common origin.
- For each (thread, disinformation event) pair (i, j), let
    - $t_{i,j}^0$: time of origin post of the thread i.
    - $\tau_{i,j}$: the time of the first rebuttal if the thread (i, j) is ever rebutted.
    - $Y_{i,j,t_{i,j}^0-1} = 0$.

Baseline Model Simulation For each disinformation event j, we run many simulations until a termination criteria is satisfied. Table 6 reports the average statistics across all the simulations.

For each disinformation event j:

1. Start the simulation at $t = t_0^j$
2. For each thread i, if $t \geq t_{i,j}^0$
   (a) Calculate $\mu_{i,j,t}$ using Equation (1) and the estimates from Table 5's final column.
   (b) Simulate post count using a Poisson distribution with mean $\mu_{i,j,t}$ to obtain $Y_{i,j,t}$.
3. Continue to the next period: calculate the total number of posts across all threads at time t. If this total is
   - Less than or equal to one: go to step 4
   - Otherwise, set $t = t + 1$ and go back to step 2
4. Termination: Check the termination criteria. If it is satisfied, stop.[33] Otherwise, go back to step 1 and start a new simulation.
5. Output statistics: Return the average statistics over all of the performed simulations for disinformation event j.

Network-based Labeling Simulation These simulations follow the baseline simulations with one key difference: the value of $\tau_{i,j}$.

Let $\tau_{i,j} = \bar{\tau}_j$ be the time when labeling begins using our algorithm, i.e., the time of the 10^{th} original post of the disinformation event j, $t_{10,j}^0$. As we consider the impact of the adoption of this approach by the social media platform in a centralized fashion, we assume that all posts on all threads are labeled as disinformation after $\bar{\tau}_j$.

[33] For our termination criteria, we construct a moment (a moving average) from all the performed simulations. If incorporating the last simulation into the moment changes it less than threshold of $1e^{-3}$, we stop.

B Additional Results

B.1 Section 3.1

In this section, we first report the confusion matrix of our main model reported in 2. We then report the estimation results corresponding to a classifier which includes all the account characteristics and does not use elastic net to choose a subset of them.

	classified Ordinary	classified Unsafe	classified Pro-regime
Ordinary accounts	correct	incorrect	incorrect
Unsafe accounts	incorrect	correct	incorrect
Pro-regime accounts	incorrect	incorrect	correct

Table B.5: Structure of confusion matrix

$$\begin{bmatrix} 138 & 9 & 0 \\ 10 & 132 & 1 \\ 1 & 0 & 140 \end{bmatrix}$$

Notes: Total accuracy: 95.13%

Table B.6: Confusion matrix of baseline model

	Unsafe		pro-regime	
	coef	std err	coef	std err
constant	-0.03	0.52	-2.37	0.60
log(Unsafe Following Score)	-0.70	0.58	-27.76	0.88
log(Unsafe Followers Score)	8.77	0.63	5.72	0.71
log(Unsafe Reposts Score)	-0.87	0.40	-7.31	1.47
log(Unsafe Reposted Score)	4.51	0.41	-7.43	0.94
log(pro-regime Following Score)	-4.28	0.78	19.88	1.01
log(pro-regime Followers Score)	-2.72	0.69	6.76	0.97
log(pro-regime Reposts Score)	-8.21	2.41	-5.39	0.26
log(pro-regime Reposted Score)	4.51	0.52	15.55	0.38
Degree Followers Centrality	-13.45	9.54	0.76	8.15
Eigen Followers Centrality	11.94	7.75	22.90	1.32
Betweenness Followers Centrality	-0.74	63.01	-0.09	58.43
Followers to Following Ratio	5.90	605.87	11.60	3.71
Account Age	-1.81	0.58	0.66	0.53
Is New Account	8.47	0.48	6.88	0.65
% Change Followers	16.79	2.50	8.17	2.05
% Change Following	-1.76	0.29	-1.38	0.25
New Followers Rate	-14.33	17.96	4.09	5.62
New Following Rate	10.58	1.75	3.11	0.92
New Reposts Sent	-5.70	14.26	-3.77	36.65
New Reposts Received	3.54	12.36	1.63	87.91
New Quote Posts Sent	3.37	30.75	1.41	145.35
New Quote Posts Received	1.70	41.83	0.76	61.97
New Replies Posts Sent	-1.05	4.01	-1.98	8.06
New Replies Posts Received	6.61	15.05	4.82	11.04
New Posts Sent	4.34	22.98	1.13	61.26
Post Rate	4.41	18.32	0.34	37.51
Reposts Sent Rate	1.59	17.21	-0.22	34.45
Reposts Received Rate	3.24	11.27	1.92	46.03
Quote Posts Sent Rate	2.86	24.37	0.80	65.16
Quote Posts Received Rate	-0.02	42.50	0.45	48.30
Replies Sent Rate	-1.66	6.05	-2.62	9.70
Replies Received Rate	1.99	14.11	5.73	10.83
Proportion Reposts	-4.10	0.42	3.87	0.44
Proportion Quote Posts	-7.36	1.71	-0.43	1.22
Proportion Replies	-5.24	0.58	-5.54	0.47
Followers to Following Near 1	1.37	0.49	1.27	0.22
New Account x Followers Rate	-8.23	7.98	-4.16	45.61
New Account x Reposts Sent Rate	4.87	2.03	0.89	15.83
New Account x Reposts Received Rate	4.59	10.82	2.26	1114.25
New Account x Quote Posts Sent Rate	-3.12	1.40	-7.10	16.34
New Account x Quote Posts Received Rate	6.04	12.24	2.99	1375.03
New Account x Replies Sent Rate	-9.82	2.01	-5.63	10.74
New Account x Replies Received Rate	-8.54	3.88	-4.27	68.26
New Account x Proportion Reposts	-7.52	0.55	-9.10	0.73
New Account x Proportion Quote Posts	-26.88	2.51	2.60	1.51
New Account x Proportion Replies	-4.31	0.81	-1.56	0.80
pro-regime Hashtag Score	3.41	1.19	-2.29	0.69
No. Observations:	1,004			
Log-Likelihood:	-0.10			
Pseudo R-squ.:	0.95			

Notes: This table shows the non-regularized multinomial logistic regression coefficients for the baseline model. All the account characteristics are used for classification.

Table B.7: Non-regularized baseline model

Category	Precision	Sensitivity
Ordinary	90.8%	93.9%
Unsafe	93.5%	90.9%
pro-regime	100.0%	99.3%

(a) Precision and Sensitivity

$$\begin{bmatrix} 138 & 9 & 0 \\ 13 & 130 & 0 \\ 1 & 0 & 140 \end{bmatrix}$$

(b) Confusion matrix

Notes: These tables report measures of performance of the baseline model without regularization, when all of the account characteristics are used for classification.

Table B.8: Precision, sensitivity and confusion matrix for the non-regularized baseline model

B.2 Section 3.2

End of training period	# of disinfo	Same period for test & train data Threshold # of unsafe initiators 5	6	7	8	Test data from complete period Threshold # of unsafe initiators 5	6	7	8
September 15, 2022	3	5/1	3/0	2/0	0/0	6/4	4/1	3/0	2/0
	6								
October 1, 2022	3	7/4	5/1	4/0	3/0	8/5	7/1	3/0	1/0
	6								
October 15, 2022	3	6/3	3/1	2/0	0/0	5/1	2/0	2/0	0/0
	6								
November 1, 2022	3	6/2	5/1	2/0	0/0	6/1	4/0	3/0	1/0
	6	8/3	8/0	7/0	6/0	8/3	8/2	7/0	7/0
November 15, 2022	3	8.2	7/1	2/0	1/0	7/1	6/0	3/0	0/0
	6	8/4	7/1	7/0	7/0	8/2	8/1	7/0	6/0
December 1, 2022	3	8/3	8/1	5/0	5/0	8/2	5/0	3/0	1/0
	6	8/3	8/2	7/0	5/0	8/3	8/1	8/0	7/0
December 15, 2022	3	8/3	8/0	7/0	5/0	8/1	8/0	5/0	1/0
	6	8/3	8/0	8/0	6/0	8/2	7/0	7/0	5/0
January 1, 2023	3	8/6	8/2	6/0	3/0	8/6	8/0	4/0	1/0
	6	8/3	8/1	7/0	5/0	8/1	8/0	7/0	5/0
January 15, 2023	3	8/6	8/2	7/0	2/0	8/6	8/0	4/0	1/0
	6	8/3	8/1	8/0	8/0	8/2	8/1	8/0	8/0
February 1, 2023	3	8/3	8/1	8/0	2/0	8/3	7/0	5/0	3/0
	6	8/1	8/0	8/0	5/0	8/1	8/1	7/0	6/0
February 15, 2023	3	8/4	8/1	6/0	4/0	8/4	7/0	5/0	4/0
	6	8/1	8/1	8/0	6/0	8/0	8/0	8/0	6/0
March 1, 2023	3	8/4	8/1	6/0	3/0	8/4	8/1	6/0	3/0
	6	8/0	8/0	8/0	7/0	8/0	8/0	8/0	7/0

Notes: This table reports the number of disinformation (out of 8) and true news (out of 10) started on X that are classified as disinformation, as we vary the following inputs to our proposed network-based approach: 1) last day of training period—each row of the table; 2) number of disinformation events used for training—the first 3 disinformation events versus the first 6, the two sub-rows within each row; 3) last day of testing period—the left block uses the same date as training data and the right block uses the data until the date of the disinformation event being tested; 4) the minimum required number of accounts classified as unsafe, among the first 10 initiators of the news being tested, to detect the news as disinformation—four columns in each block: 5,6,7 and 8. Each cell denotes the number of disinformation/true news events that are classified as disinformation. Empty cells are those where a disinformation events in the training set has occurred after the end of the corresponding training period.

Table B.9: Number of classified disinformation & true news events as disinformation

B.3 Section 5.1

This section reports estimation and model performance results for two other models. The first set, Tables B.10-B.12, are for the non-manipulable model and second set, Tables B.13-B.16 are for the model with non-network characteristics only (easily manipulable). Tables B.13-B.14 (B.15-B.16) correspond to regularized (non-regularized) results for the model with non-network characteristics only.

Category	Precision	Sensitivity
Ordinary	90.0%	91.8%
Unsafe	91.5%	90.2%
pro-regime	100.0%	99.3%

(a) Precision and Sensitivity

$$\begin{bmatrix} 135 & 12 & 0 \\ 14 & 129 & 0 \\ 1 & 0 & 140 \end{bmatrix}$$

(b) Confusion matrix

Notes: These tables report measures of performance of the model with network only variables presented in Section 5.1. Total accuracy of the model is 93.7%.

Table B.10: Precision, sensitivity and confusion matrix for Network only Variables (Non-Manipulable)

	Unsafe		pro-regime	
	coef	std err	coef	std err
constant	-1.88	0.27	-1.51	0.38
log(Unsafe Following Score)	-2.00	0.55	-46.14	0.61
log(Unsafe Followers Score)	7.46	0.64	2.56	0.53
log(Unsafe Reposts Score)	-0.21	0.36	-1.79	0.60
log(Unsafe Reposted Score)	2.54	0.36	-8.43	0.79
log(pro-regime Following Score)	-5.82	0.67	41.02	0.90
log(pro-regime Followers Score)	0.63	0.60	-3.26	0.80
log(pro-regime Reposts Score)	-1.07	1.58	-6.15	0.24
log(pro-regime Reposted Score)	5.18	0.44	16.00	0.33
Degree Followers Centrality	-5.31	1.26	-37.36	21.99
Eigen Followers Centrality	20.59	11.70	152.45	1091.84
Betweenness Followers Centrality	-0.72	1.55	-2.39	8.31
No. Observations:	1,004			
Log-Likelihood:	-0.11			
Pseudo R-squ.:	0.94			

Notes: This table shows the non-regularized multinomial logistic regression coefficients for the non-manipulable model. All the account network-based characteristics are used for classification.

Table B.11: Non-regularized non-manipulable model

Category	Precision	Sensitivity
Ordinary	91.2%	91.8%
Unsafe	92.2%	90.9%
pro-regime	99.3%	100.0%

(a) Precision and Sensitivity

$$\begin{bmatrix} 135 & 11 & 1 \\ 13 & 130 & 0 \\ 0 & 0 & 141 \end{bmatrix}$$

(b) Confusion matrix

Notes: These tables report measures of performance of the non-manipulable model without regularization, when all of the network-based account characteristics are used for classification. Total accuracy is 94.2%.

Table B.12: Precision, sensitivity and confusion matrix for the non-regularized non-manipulable model

	Unsafe		pro-regime	
	coef	std err	coef	std err
Account Age	-0.58	0.19	-0.21	0.37
Is New Account	1.25	0.28	1.48	1.24
% Change Followers	0.54	0.35	1.13	0.91
% Change Following	-1.84	0.61	0.18	0.73
New Followers Rate	-2.88	0.77	-1.45	0.89
New Following Rate	0.83	2.10	0.38	0.24
New Reposts Sent	1.40	0.51	0.57	0.35
New Reposts Received	0.26	354.66	3.22	3.22
New Replies Posts Sent	1.31	2.54	2.00	2.00
New Posts Sent	2.82	13.23	3.26	2.48
Post Rate	2.02	1.42	1.02	0.67
Reposts Sent Rate	0.71	4.84	18.38	18.21
Reposts Received Rate	0.25	11.30	71.09	71.09
Quote Posts Received Rate	-0.06	11.77	24.09	24.15
Replies Sent Rate	-1.03	1.13	2.08	3.11
Replies Received Rate	-0.51	11.72	7.14	7.65
Proportion Reposts	0.98	5.08	29.64	28.60
Proportion Quote Posts	-3.42	7.52	9.19	11.97
Proportion Replies	-1.98	8.33	13.16	13.16
Followers to Following Near 1	0.48	9.44	37.96	37.49
New Account x Quote Posts Sent Rate	-0.09	10.86	7.30	7.39
New Account x Proportion Reposts	-1.76	0.47	-1.52	0.21
New Account x Proportion Quote Posts	-0.27	7.17	35.60	35.60
New Account x Proportion Replies	-0.01	1.28	34.42	34.42
pro-regime Hashtag Score	-2.41	7.69	1052.03	1052.03
No. Observations:	1,004			
Log-Likelihood:	-0.21			
Pseudo R-squ.:	0.87			

Notes: This table shows the multinomial logistic regression coefficients for model that uses non-network characteristics only (easily manipulable), regularized with an elastic net with equal L1 and L2 penalties. Factors with point estimates of zero were pushed to zero by the elastic net. The coefficients for the ordinary category are normalized to zero.

Table B.13: Model with non-network characteristics only (easily manipulable)

Category	Precision	Sensitivity
Ordinary	68.6%	78.9%
Unsafe	74.4%	69.2%
pro-regime	78.3%	71.6%

(a) Precision and Sensitivity

$$\begin{bmatrix} 116 & 19 & 12 \\ 28 & 99 & 16 \\ 25 & 15 & 101 \end{bmatrix}$$

(b) Confusion matrix

Notes: These tables report measures of performance of the model with non-network account characteristics only with regularization. Total accuracy is 73.3%.

Table B.14: Precision, sensitivity, and confusion matrix for the model with non-network characteristics only (easily manipulable)

	Unsafe		pro-regime	
	coef	std err	coef	std err
constant	0.93	0.41	-0.68	0.55
Followers to Following Ratio	1.68	0.62	7.16	0.68
Account Age	-0.78	0.57	-3.02	0.85
Is New Account	3.34	0.39	3.56	1.40
% Change Followers	17.53	0.40	0.22	0.93
% Change Following	-1.72	0.64	0.40	0.94
New Followers Rate	-48.43	0.76	-59.59	1.00
New Following Rate	10.89	2.33	-19.67	0.26
New Reposts Sent	2.89	0.52	-1.23	0.37
New Reposts Received	14.24	464.92	-8.16	3.68
New Quote Posts Sent	4.10	0.55	0.17	0.52
New Quote Posts Received	-13.78	0.21	-15.70	0.26
New Replies Posts Sent	1.79	2.44	-10.35	2.05
New Replies Posts Received	4.79	0.28	-2.80	0.25
New Posts Sent	23.27	13.78	4.18	2.73
Post Rate	16.84	1.49	11.69	0.72
Reposts Sent Rate	1.13	13.97	8.34	36.26
Reposts Received Rate	16.70	10.79	-4.92	87.27
Quote Posts Sent Rate	2.06	29.91	-0.90	143.89
Quote Posts Received Rate	-14.45	39.16	-15.90	59.87
Replies Sent Rate	-10.09	3.88	-8.66	7.97
Replies Received Rate	-12.08	13.83	-11.83	10.87
Proportion Reposts	0.61	22.47	3.74	60.58
Proportion Quote Posts	-4.41	18.19	-6.37	36.85
Proportion Replies	-2.01	17.17	3.25	33.91
Followers to Following Near 1	0.70	9.62	0.56	45.64
New Account x Followers Rate	6.69	23.43	-3.50	63.13
New Account x Reposts Sent Rate	11.26	40.25	1.42	46.40
New Account x Reposts Received Rate	6.33	5.93	0.30	9.57
New Account x Quote Posts Sent Rate	-12.49	12.60	-19.73	10.64
New Account x Quote Posts Received Rate	4.83	0.28	-0.45	0.36
New Account x Replies Sent Rate	5.62	1.28	9.67	0.70
New Account x Replies Received Rate	-2.76	0.41	1.92	0.38
New Account x Proportion Reposts	-4.10	0.49	-6.18	0.22
New Account x Proportion Quote Posts	-1.34	7.50	6.30	39.02
New Account x Proportion Replies	-2.49	1.79	-4.12	21.01
pro-regime Hashtag Score	-0.44	8.17	5.40	1107.35
No. Observations:	1,004			
Log-Likelihood:	-0.18			
Pseudo R-squ.:	0.90			

Notes: This table shows the non-regularized multinomial logistic regression coefficients for the model with non-network account characteristic only. All the non-network account characteristics are used for classification.

Table B.15: Non-regularized model with non-network characteristics only (easily manipulable)

Category	Precision	Sensitivity
Category	Precision	Sensitivity
Ordinary	75.8%	81.0%
Unsafe	74.3%	74.8%
pro-regime	87.7%	80.9%

(a) Precision and Sensitivity

$$\begin{bmatrix} 119 & 23 & 5 \\ 24 & 107 & 11 \\ 13 & 14 & 114 \end{bmatrix}$$

(b) Confusion matrix

Notes: These tables report measures of performance of the model with non-network-characteristics only (easily manipulable) without regularization, when all of the non-network account characteristics are used for classification. Test accuracy is 78.9%.

Table B.16: Precision, sensitivity and confusion matrix for the non-regularized model with non-network-characteristics only (easily manipulable)