

The Impact of Prevention and Control Policies for Major Public Health Emergencies on Public Sentiment: Causal Inference Based on User Comments

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Abstract

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Full Text

How Public Health Emergency Prevention and Control Policies Affect Public Sentiment: A Causal Inference Based on User Comments

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Abstract

[Purpose/Significance] During the prolonged duration of major public health emergencies, how to timely perceive, effectively quantify, and continuously track the impact of government prevention and control policy combinations on public cognition and sentiment represents an urgent challenge for monitoring, early warning, and emergency response. **[Method/Process]** Grounded in the Emotions as Social Information (EASI) theory, this study proposes a novel methodology integrating the BERTopic topic model with Multiple Linear Regression (MLR) and Regression Discontinuity in Time (RDiT) to conduct causal inference on over 310,000 high-frequency COVID-19-related user comments from Sina Weibo in 2020, aiming to reveal the impact of COVID-19 containment policy combinations on the public. **[Results/Conclusions]** The findings indicate that: (1) The implementation of COVID-19 containment policy combinations caused a significant decrease in public sentiment values among Weibo users by 0.07–0.12 units around February 20, 2020, and a significant rebound of 0.06–0.08 units around April 28, 2020; (2) The policy combinations exhibited heterogeneous effects on users' cognition and sentiment, with policies involving individuals and featuring coercive measures more likely to trigger heated online discussions and significantly depress public sentiment; (3) The causal chain of policy intervention → user hot topics → sentiment fluctuations constructed through this analysis enables retrospective inference of policy implementation effectiveness. This research not only opens new avenues for evidence-based governance in public health policy evaluation but also provides innovative tools for public-oriented real-time pandemic monitoring.

Keywords: containment policy, public sentiment, Multiple Linear Regression, Regression Discontinuity in Time, BERTopic

Enhancing the scientific and democratic nature of policy decision-making represents an essential requirement for improving decision-making mechanisms, policy quality, and effectiveness, as well as a crucial measure for advancing the modernization of national governance in the new era. The “14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives Through 2035” explicitly states in the section on “Comprehensively Advancing Healthy China Construction” that China must “improve the monitoring, early warning, and response mechanisms for public health emergencies... and enhance the capacity to respond to such emergencies.” As the most severe infectious

disease globally in nearly a century, the novel coronavirus pneumonia epidemic (hereinafter referred to as COVID-19) is characterized by rapid transmission, extensive infection scope, profound impact, and formidable prevention and control challenges [1][2]. Following the outbreak, spread, and persistence of the pandemic, governments worldwide have implemented diverse intervention policy combinations ranging from epidemic control to economic preservation [3][4]. Among these, containment and lockdown represent the most common policy instruments, including stay-at-home orders, social distancing mandates, school closures, restrictions on public gatherings, and travel limitations. Although these containment policies effectively reduced COVID-19 infection rates, the prolonged pandemic inevitably imposed increasing psychological and physiological impacts on the public. How to innovate monitoring approaches to timely perceive, effectively quantify, and continuously track the influence of different prevention and control policy combinations on public cognition and sentiment constitutes both a frontier in big data-driven evidence-based decision-making research and a focal point for governments at all levels to further improve multi-channel pandemic monitoring and early warning systems and implement scientifically precise epidemic prevention. In this regard, researchers at Oxford University's Blavatnik School of Government developed the "Oxford COVID-19 Government Response Tracker," establishing a standardized indicator system that collects publicly available data across five dimensions—containment, economic relief, healthcare, vaccination, and others—to compare the speed and intensity of government responses across countries [3][5], enabling the tracking of variations in policy intervention strength among different nations and local governments. Some scholars have also examined the interactive logic between netizen messages and government responses [6], as well as the role of online governance platforms in public sentiment perception and mitigation [7], from a digital governance perspective by analyzing online public opinion data gathered from China's "Leadership Message Board" platform. Comparatively, however, research quantitatively tracking the implementation impacts of epidemic prevention policies from the public perspective remains scarce.

This study adopts a systems perspective, conceptualizing the implementation of COVID-19 containment policies as a dynamic cyclical process of policy subjects acting upon policy objects. Grounded in the Emotions as Social Information (EASI) theory, it analyzes the impact of containment policy implementation on public psychology from both cognitive and emotional dimensions. Specifically, by collecting over 310,000 high-frequency user comments related to COVID-19 from Sina Weibo, the study proposes a methodology integrating cutting-edge natural language processing technology—the BERTopic topic model—with Multiple Linear Regression (MLR) and Regression Discontinuity in Time (RDiT) to examine how public cognitive foci (semantic topic distribution of comments) and emotions (sentiment polarity changes in comments) reflected in social media posts fluctuate under policy influence, thereby assisting government decision-makers in quantifying the effects of different types of prevention and control policies on psychological cognition and emotional orientation. The potential

value of this research manifests in two aspects: (1) Through technological governance approaches, it organically connects macro-level containment policy combinations with individual public experiences, opening new pathways for intelligent and precise real-time monitoring of policy impact assessment during major public health emergencies; (2) The proposed analytical framework and quantitative methods feature direct public engagement, data-driven insights, and retrospective inference characteristics, which not only contribute to theoretical innovation in data-driven evidence-based policy decision-making but also provide quasi-real-time analytical tools for public health emergency prevention and social governance.

1.1 COVID-19 Prevention Policies and Online Governance

Existing research indicates that focusing events are incidents that impact specific regions and groups while capturing public and decision-maker attention, typically causing actual harm to certain populations' interests and potential threats to others [8][9]. As a major public health emergency, COVID-19 exhibits characteristics of sudden onset, rapid development, and widespread impact, alongside features of unpredictability, covert transmission, and uncertain outcomes [10]. From Lindblom's perspective of incremental decision-making, government-issued epidemic containment policies demonstrate two prominent features: First, decision-making progresses incrementally and becomes increasingly detailed, as the epidemic's development cannot be fully controlled by human effort, necessitating adaptive prevention and control strategies responsive to timing and circumstances; Second, policy effectiveness remains uncertain, as each containment measure carries both advantages and disadvantages, forcing decision-makers to settle for "satisfactory solutions" under conditions of time pressure and limited information. From a policy evolution standpoint analyzed through the Multiple Streams Framework, the formulation and implementation of COVID-19 containment policies result not from single-factor causation but from the convergence of problem streams, policy streams, and political streams at particular moments, with problem streams exerting substantial influence on policy direction. With the widespread adoption of mobile internet, user comments and messages on social media regarding the epidemic represent not only real-time expressions of netizens' inner thoughts but also digital "barometers" of public opinion trends. Currently, social media has become a crucial channel for governments to observe public sentiment and gather wisdom, while online governance has gradually extended from pre-policy consultation to tracking policy implementation effectiveness. Real-time collection of netizens' policy-related opinions through social media's high-frequency interactive features, combined with insights into diverse public perspectives on policies, not only facilitates more inclusive decision-making but also provides multidimensional, quantitative evidence for evaluating policy execution outcomes.

1.2 Emotions as Social Information Theory and Netizens' Emotional Social Effects

Since ancient Greek times, Aristotle argued that emotions arise from individuals' interpretations and evaluations of events in the world through cognition. Social constructionist theories of emotion posit that groups function as "generalized others," where the attitudes of numerous participants in a shared process influence individuals' behavioral choices [11]. In the mobile internet era, social media serves as both a crucial channel for personal cognition of the external world and a vehicle for aggregating individual cognitions and shaping social identity. Internet user comments encode not only semantic information but also emotional content, with the social effects of emotions explicable through the Emotions as Social Information (EASI) theory. Rooted in the social functionalist perspective on emotions and proposed by Van Kleef (2009), this theory contends that emotions constitute a form of social information, wherein individuals' emotional expressions simultaneously reflect their cognitions and attitudes. In interpersonal communication, observers acquire understanding of others' emotional information through two primary pathways: affective reactions and inferential processing. The former directly triggers observers' emotional states, generating "interpersonal effects" at the emotional level, while the latter incorporates individuals' emotional information as inputs for social decision-making, producing "interpersonal effects" at the cognitive level [12][13]. Furthermore, the social effects of emotions are moderated by two variables: depth of information processing, which characterizes observers' information processing capacity, and perceived appropriateness, which reflects observers' judgments of the suitability of others' emotional expressions based on social norms in specific contexts. Research by Shi Mi et al. (2017) [14] on emotional contagion pathways in the spread of online collective behavioral intentions confirms that in online contexts, emotional contagion does not directly influence collective behavioral intentions but rather affects their expression through two routes: unconscious contagion of emotional experiences and conscious social comparison of information perception. This indirectly corroborates that user comment behavior on social media is influenced by both trending topics in public posts and the emotional orientation of popular posts. Therefore, tracking the rotation of hot topics triggered by policy interventions and the emotional fluctuations in popular comments through social media can effectively gauge public social identification with policies and emotional cognition.

1.3 Analytical Framework Based on Systems Perspective

From a systems perspective, COVID-19 prevention policy combinations constitute a complex social system formed by the interaction of policy subjects, policy objects, and policy environments [15]. This system can be deconstructed for analysis as a dynamic cycle among three variables: input, output, and feedback. Input can be conceptualized as the convergence of problem streams, policy streams, and political streams; output comprises the policy combinations and

implementation measures issued by policy subjects; and feedback represents the cyclical interaction between policy objects affected by interventions and policy subjects. The COVID-19 outbreak accelerated the shift of public communication channels from offline to online, and understanding netizens' cognitive foci and emotional fluctuations regarding prevention policies through social media user comments can provide quasi-real-time feedback for policy improvement and optimization from three dimensions—political streams, policy streams, and problem streams—while also opening new avenues for pre-policy assessment and mid-implementation monitoring (as illustrated in Figure 1 [Figure 1: see original paper]).

Figure 1 Framework of Epidemic Prevention Policy Impact on Social Media Users from a Systems Perspective

2.1 Data Sources

To explore the complex impacts of COVID-19 containment policies on netizens' epidemic cognition and emotional tendencies, this study collected COVID-19-related user comment texts from multiple accounts on Sina Weibo, a prominent Chinese social media platform, as the primary dataset. The selection of Sina Weibo as the data source for netizen comments rests on two main considerations: First, according to Sina Weibo's 2020 User Development Report, by September 2020, the platform had reached 511 million monthly active users and 224 million daily active users, with post-90s and post-00s generations accounting for nearly 80% of the user base. Throughout 2020, continuous trending topics attracted widespread attention, tracking, and discussion among young users, highlighting the platform's strong public opinion attributes. Second, in 2020, the number of verified government accounts on Weibo exceeded 140,000, with total followers surpassing 3 billion. During the pandemic, Weibo users viewed epidemic-related information 16.1 billion times daily, with high-frequency interactions capable of quasi-real-time reflection of public cognitive foci and emotional fluctuations. To ensure diverse and representative comment samples, the study selected 12 prominent Weibo accounts spanning government (Central Committee of the Communist Youth League, CCTV), news media (People's Daily, Wuhan Release, China Daily, Sohu News, Guancha, Global Times, People.com.cn, The Paper), and community influencers (Siman Nan, Dr. Zhang Wenhong), collecting user comments on pandemic-related posts from January 1 to December 31, 2020. These accounts had follower counts ranging from 1.85 million to 150 million, demonstrating high popularity and frequent engagement. Furthermore, the study set a maximum of 250 top comments per pandemic-related post to capture representative comments with high netizen endorsement, then randomly selected 3,000 posts from the eligible accounts to collect comment texts, resulting in a dataset of 315,213 records across 28 fields. After cleaning the raw data by removing duplicate texts and overly short comments, 313,912 data entries remained for subsequent analysis.

2.2 Variable Selection and Definition

For the collected Weibo user pandemic comment data, we first employed an open-source Baidu sentiment analysis tool to analyze the sentiment orientation of each comment, calculating the Daily Average Sentiment of Weibo Users (DASWU) as the dependent variable in this study. Second, to address exogenous factors influencing public sentiment, we identified independent variables from multiple dimensions including epidemic trends, prevention policies, and economic indicators. Regarding epidemic changes, we selected metrics such as daily new infections and daily new deaths to characterize epidemic fluctuations. For prevention policies, we utilized open national-level policy response data from Oxford University's "Oxford COVID-19 Government Response Tracker," selecting eight policies from five primary categories (containment, economic relief, healthcare, vaccination, and others) and 15 secondary policy instruments: school closures, cancellation of public events, public transport restrictions, international travel controls, vaccination policies, testing policies, contact tracing, and facial covering requirements. These eight policies were chosen because most appeared in Versions 1 through 6 of the "COVID-19 Prevention and Control Protocol," ensuring typicality and representativeness. For economic indicators, we selected GDP growth rate and Consumer Price Index (CPI) to measure macroeconomic impacts. Additionally, to examine the effect of pandemic duration on public sentiment, we included Days Elapsed (DE) since the outbreak as an independent variable, along with other control variables such as Delayed Daily Average Sentiment of Weibo Users (DDASWU), as illustrated in Table 1 :

Table 1 Variable Definitions and Data Sources

Given that the pandemic's progression from outbreak to persistence exhibits wave-like characteristics, government intervention policies change over time, and public sentiment may fluctuate accordingly. Based on changes in government epidemic prevention policies, the research period was divided into three stages: Stage 1, January 1–February 20, 2020, marked by outbreak and lockdown, characterized by the epidemic's eruption centered in Wuhan, nationwide support for Wuhan, societal-level containment, and initial epidemic control; Stage 2, February 21–April 28, 2020, representing full containment and initial recovery, featuring new local cases dropping to single digits, decisive victory in Wuhan's anti-epidemic efforts, and orderly resumption of work and production; Stage 3, April 29–December 31, 2020, encompassing full recovery and normalized prevention and control, characterized by consolidated anti-epidemic achievements, comprehensive work resumption, and a shift toward normalized epidemic prevention and control with diagnostic focus moving to nucleic acid testing. To investigate causal relationships between public sentiment and policy interventions alongside other variables, subsequent analyses employ daily units of time.

2.3 Methodology and Model Design

Considering that the collected data primarily consist of text data supplemented by numerical data, this study proposes a quantitative research approach integrating Multiple Linear Regression (MLR), Regression Discontinuity in Time (RDiT), and the BERTopic topic model, as illustrated in Figure 2 [Figure 2: see original paper]:

Figure 2 Research Framework for COVID-19 Containment Policy Impact on Public Sentiment

The research object of this study comprises user-posted comment texts related to COVID-19, aiming to comprehensively apply cutting-edge natural language processing technologies and novel causal inference methods to quantitatively analyze the impact of epidemic containment and control policies issued by China's central government on public psychological sentiment. To achieve this research objective, we first developed Python code to invoke the sentiment orientation analysis API of Baidu AI Cloud's NLP module, quantifying the sentiment polarity of user comment texts through text sentiment analysis technology (0=negative, 1=neutral, 2=positive). Second, we employed the calculated Daily Average Sentiment for Weibo Users (DASWU), incorporating temporal factors, as the dependent variable, with COVID-19 containment policy combinations and other influencing factors serving as independent or control variables, using Multiple Linear Regression (MLR) to explore key factors affecting user sentiment fluctuations across different stages. Third, treating the stage transitions of COVID-19 containment policies as natural experimental scenarios and pandemic duration as the assignment variable, we applied Regression Discontinuity in Time (RDiT) analysis using the three stage transition dates (February 20 and April 28) as cut-offs to examine the causal impacts of specific containment policies on public sentiment fluctuations at these two breakpoints. Finally, we introduced BERTopic, a topic modeling technique based on Transformer-based Bidirectional Encoder Representations (BERT) embeddings, to identify pandemic-related hot topics of public concern and their changes across stages, thereby tracing the primary drivers of user sentiment variations. The necessity of incorporating RDiT and BERTopic as research methods is elaborated below.

2.3.1 Regression Discontinuity in Time

Differing from traditional regression discontinuity designs, Regression Discontinuity in Time (RDiT) employs time as the assignment variable, inferring causal relationships between intervention and outcome variables by determining whether the outcome variable exhibits a jump at the time point when policy intervention occurs. This method has been applied by researchers to examine the impact of public transportation on alleviating road congestion [16], evaluate the effectiveness and heterogeneity of housing purchase restriction policies [17], and analyze corporate survival resilience under COVID-19 shocks [18]. This study applies RDiT to assess whether specific epidemic containment policies

significantly influence fluctuations in public sentiment values, based on two considerations: (1) The diverse types of epidemic containment and control policies issued by the national government in 2020 had varying implementation times, and employing RDIT can effectively avoid interference from other policy factors on the results; (2) Time variables feature uniform distribution characteristics, and using time as the assignment variable ensures unchanged distribution frequency, though with relatively smaller sample sizes near the cutoff. To this end, we first use Equation (2) to evaluate whether a jump exists in Weibo users' sentiment values before and after the cutoff date, where in Equation (1), $\lim_{d \rightarrow 0} \Delta = 0$ represents the Daily Average Sentiment of Weibo Users (DASWU), and d denotes the number of days before or after the cutoff date. Subsequently, we construct the baseline RDIT model as shown in Equation (2):

In Equation (2), Δ represents the dependent variable—Daily Average Sentiment of Weibo Users (DASWU), Δ_t denotes the sentiment cutoff value at time point t , signifies other control variables, and ϵ_t represents other unobserved time-varying factors correlated with the dependent variable within the observation window (presented as polynomials that appear continuous and smooth at the cutoff). In other words, observations before the time cutoff are unaffected by the specific policy, while observations after the cutoff are influenced by the policy intervention, constituting a sharp discontinuity. Following recommendations from Gao Yun et al. (2022) [19], we employ both global and local variable estimation methods to estimate the coefficient affecting sentiment changes at time point t . The user comments collected in this study constitute high-frequency data, and the calculated Daily Average Sentiment of Weibo Users can effectively reflect subtle changes in public sentiment under policy interventions.

2.3.2 BERTopic Topic Model

BERTopic represents a new-generation topic model that integrates BERT embeddings and TF-IDF to create dense clusters [20]. Compared with LDA topic models, its advantages include: (1) Utilizing Google's Transformer-based Bidirectional Encoder Representations pre-trained model, which is broadly applicable across languages [21]; (2) Through hierarchical and density-based clustering, employing class-based TF-IDF to extract thematically richer and more distinctive topic words for each cluster [22]. This study first applies the BERTopic model to analyze the 310,000 Weibo user comment texts obtained in Section 2.1, identifying pandemic-related hot topics of user concern at each stage based on the frequency of clustered semantic groups, particularly focusing on topic changes across stage transitions. Second, we combine the identified topics with regression discontinuity analysis to infer the cognitive reasons behind user sentiment fluctuations induced by COVID-19 prevention policy interventions.

3 Analysis and Discussion

This section first presents stage-specific multiple regression analysis results to identify exogenous factors significantly affecting daily average public sentiment

values across the three stages. Second, it applies regression discontinuity in time analysis to examine the cutoff treatment effects at the transitions between Stages 1-2 and Stages 2-3, inferring the causal impacts of containment policy implementation on Weibo users' sentiment. Finally, based on BERTopic topic modeling of user comments, it identifies hot topics discussed by Weibo users and their influence on user sentiment at different stages, constructing a causal chain from the eight containment policies to user hot topics to sentiment changes.

3.1 Multiple Regression Analysis

To analyze public sentiment fluctuations across the three stages (outbreak and lockdown, containment and recovery, normalized prevention and control), we plotted boxplots of Weibo users' sentiment distribution for each stage as shown in Figure 3 [Figure 3: see original paper]:

Figure 3 Distribution Line Chart of Weibo Users' Sentiment Fluctuations Across Three Stages

Figure 3 reveals that daily average sentiment scores among Weibo users generally declined from Stage 1 to Stage 2, then increased significantly from Stage 2 to Stage 3, indicating that COVID-19 containment policies indeed caused fluctuations in public sentiment.

Using Daily Average Sentiment of Weibo Users (DASWU) as the dependent variable and 24 factor variables across four categories—including eight epidemic containment policy variables implemented by the government, three epidemic trend impact variables, five macroeconomic impact variables, and lagged Daily Average Sentiment of Weibo Users variables (DDASWU)—as independent variables, we employed multiple regression models to analyze the relationships between daily average sentiment scores and containment policies along with other factors across the three stages, as presented in Table 2 :

Table 2 Multiple Regression Analysis of Daily Average Sentiment Scores with Containment Policies and Other Factors Across Three Stages

Table 2 results indicate that during the outbreak and lockdown stage (January 1–February 20, 2020), regular government epidemic press conferences and facial covering policies had significant positive effects on public sentiment, while contact tracing policies exhibited significant negative impacts. In the full containment and initial recovery stage (February 21–April 28, 2020), testing policies demonstrated significant positive effects on public sentiment. Additionally, income support policies for residents also produced significant positive impacts. However, during this stage, the number of days elapsed since the epidemic's onset also showed a significant negative effect on public sentiment. In the comprehensive recovery and normalized prevention stage (April 29–December 31, 2020), the only factor significantly affecting public sentiment was the duration of the pandemic, with this effect shifting from negative to positive compared to Stage 2, reflecting that as the COVID-19 pandemic persisted and prevention

and control became normalized, the public increasingly viewed the epidemic with objective rationality, and negative sentiments gradually diminished.

Multiple regression analysis results can only identify correlational factors affecting public sentiment at different stages. The following section further employs regression discontinuity in time analysis to investigate the causal impacts of containment policies on public sentiment.

3.2 Regression Discontinuity in Time Analysis

Following recommendations from Gao Yun et al. (2022) [19] and adhering to the steps of cutoff applicability testing, cutoff treatment effect determination, and conclusion robustness testing, we conducted the first regression discontinuity analysis at the transition point between Stages 1 and 2, and the second analysis at the transition between Stages 2 and 3. The results are presented below.

(1) Regression Discontinuity Analysis at the Stage 1-2 Transition

We first plotted a scatter diagram of daily average sentiment values for Weibo users from January 1 to April 28, 2020 (covering Stages 1 and 2), as shown in Figure 4 [Figure 4: see original paper], to observe whether a sentiment value jump discontinuity exists at the stage transition point.

The figure reveals a noticeable downward shift in public sentiment values to the right of February 20, indicating a clear downward jump in sentiment at this time point. To further test for the presence of a discontinuity, we fitted linear, quadratic, cubic, and quartic models to the daily average public sentiment values from January 1 to April 28, 2020, producing the fitted plots shown in Figure 5 [Figure 5: see original paper]:

Figure 5 Simulated Regression Discontinuity Analysis for Stages 1 and 2

The four different fitting results consistently demonstrate a clear downward jump in public sentiment values, leading us to conclude that a discontinuity effect exists during the January 1–April 28, 2020 period, with policies implemented at the cutoff point exerting discontinuous impacts on public sentiment changes.

Next, we estimated the policy treatment effect at the cutoff. To ensure robustness of the estimates, we employed both local and global regression approaches. Before conducting local and global regressions, we first used the `rdwselect` function for bandwidth selection, with results presented in Table 3 :

Table 3 Bandwidth Selection for Stage 1-2 Cutoff

In Table 3, BW est. (h) represents the optimal bandwidth for both sides, BW bias (b) denotes the bias bandwidth used for bias-corrected estimator estimation, while mse and cer are two common methods in bandwidth calculation: mse (mean squared error) is suitable for point estimation bandwidth selection, and cer (coverage error rate) is appropriate for interval estimation bandwidth

selection. Therefore, this study appropriately adopts the mse method. Mserd represents bandwidth estimates with equal left and right sides, msetwo indicates bandwidth estimates with unequal left and right sides, msesum denotes bandwidth selection for the sum of regression estimates, msecomb1 is the minimum value between mserd-ended and msesum-ended bandwidths, and msecomb2 is the median selection among mserd, msesum, and msetwo. Table 3 shows that the optimal bandwidth range on the left side of the Stage 1-2 cutoff falls between 11.361–13.853, while the right side ranges from 11.361–20.265.

Next, we conducted local linear regression and local polynomial regression on the data using the msetwo method, which automatically selects bandwidth based on data characteristics. The results are presented in Table 4 :

Table 4 Local Linear and Polynomial Regression Results at Stage 1-2 Cutoff

Table 4 shows that local linear regression and quadratic regression results are statistically significant at the 95% confidence interval, with local linear and quadratic regression outperforming cubic and quartic regression. Therefore, the cutoff treatment effect determined by local regression indicates that COVID-19 containment policies implemented in Stage 1 caused a 0.09–0.1 unit decrease in public sentiment values at the cutoff.

Second, we conducted global polynomial regression on the data, with results presented in Table 5 :

Table 5 Global Polynomial Regression Results at Stage 1-2 Cutoff

In Table 5, treatment represents the treatment variable, $\text{margin_}\{\text{del}\}$ denotes the difference between the assignment variable x and the cutoff, $\text{margin_}\{\text{del}^2\}$ represents the square of this difference, and $\text{margin_}\{\text{del}^3\}$ represents the cube of this difference. The meanings of the six global polynomial regression models are shown in Table 6 :

Table 6 Meanings of Global Polynomial Regression Models

Table 5 analysis results indicate that the six global polynomial regression models demonstrate high goodness-of-fit values, with statistically significant cutoff treatment effects fluctuating within the [0.07, 0.12] range.

To select the optimal model among the six global regression models for Stages 1-2, we calculated the AIC values for each model, as presented in Table 7 :

Table 7 AIC Values for Six Global Polynomial Regression Models (Stages 1-2)

Smaller AIC values indicate better models. Table 7 shows that Model 3 (quadratic regression) has the smallest AIC value; therefore, we adopt Model 3's results as the global polynomial regression outcome for Stages 1-2.

Finally, we conducted robustness testing to confirm that the Stage 1-2 data contain only one cutoff without other discontinuities at different time points. To this end, we performed placebo tests, with P-values, regression coefficients,

and 95% confidence intervals for different cutoff selections shown in Figure 6 [Figure 6: see original paper]:

Figure 6 Placebo Tests for Different Cutoffs in Stages 1 and 2

Figure 6-A assumes four alternative cutoff locations. However, the P-values corresponding to the regression coefficients for all four placebo cutoffs (pseudo-cutoffs) exceed 0.05, indicating no cutoff treatment effects at these time points and confirming that the February 20 cutoff effect at the Stage 1-2 transition is genuine and unique.

In summary, local and global regression results demonstrate that at the Stage 1-2 transition point (February 20), COVID-19 containment policies implemented in Stage 1 indeed caused a significant decline in public sentiment values among Weibo users, with the decrease ranging from 0.07–0.12 units.

(2) Regression Discontinuity Analysis at the Stage 2-3 Transition

We first plotted a scatter diagram of daily average sentiment values from February 22 to December 31, 2020 (covering Stages 2 and 3), as shown in Figure 7 [Figure 7: see original paper], to observe whether a discontinuity exists.

Figure 7 Scatter Plot of Variable Distribution for Stage 2-3 Discontinuity Analysis

Figure 7 reveals that Stage 3 data points (orange-red) show a clear upward shift relative to Stage 2 data points (sky blue) around April 28, 2020, indicating that public sentiment among Weibo users in Stage 3 rebounded compared to Stage 2, with a relatively pronounced discontinuity effect at the stage transition.

To test for the presence of a discontinuity, we fitted linear, quadratic, cubic, and quartic models to the daily average public sentiment values from February 22 to December 31, 2020, producing the fitted plots shown in Figure 8 [Figure 8: see original paper]:

Figure 8 Simulated Regression Discontinuity Analysis for Stages 2 and 3

Figure 8 shows that four different fitting results for daily public sentiment values in Stages 2 and 3 indicate a relatively clear upward jump around April 28, 2020. Therefore, a discontinuity effect exists at this point, with policies implemented at the cutoff exerting discontinuous impacts on Weibo users' sentiment changes. Next, we estimated the policy treatment effect at the cutoff using both local polynomial regression and global polynomial regression to ensure robustness of the estimates. Before conducting local and global regressions, we first performed bandwidth selection using the `rdwselect` function, with results presented in Table 8 :

Table 8 Bandwidth Selection for Stage 2-3 Cutoff

The parameters in Table 8 share the same meanings as in Table 3. Table 8 shows that the optimal bandwidth range on the left side of the Stage 2-3 cutoff falls between 13.066–18.894, while the right side ranges from 15.462–56.509.

Next, we conducted local linear regression and local polynomial regression on the data using the `msetwo` method, which automatically selects bandwidth based on data characteristics. The results are presented in Table 9 :

Table 9 Local Linear and Polynomial Regression Results at Stage 2-3 Cutoff

Table 9 shows that whether linear, quadratic, cubic, or quartic regression, local linear regression results are statistically significant at the 95% confidence interval, indicating a pronounced discontinuity effect at the Stage 2-3 transition point, with effect values fluctuating within the $[0.055, 0.079]$ range.

Subsequently, we applied global polynomial regression analysis to the data, with results presented in Table 10 :

Table 10 Global Polynomial Regression Results at Stage 2-3 Cutoff

The parameters in Table 10 share the same meanings as in Table 5. To select the optimal model among the six global regression models for Stages 2-3, we calculated the AIC values for each model, as presented in Table 11 :

Table 11 AIC Values for Six Global Polynomial Regression Models (Stages 2-3)

Smaller AIC values indicate better models. Table 11 shows that Model 5 (cubic regression) has the smallest AIC value; therefore, we adopt Model 5's results as the global polynomial regression outcome for Stages 2-3.

Finally, we conducted robustness testing to verify that the cutoff during the Stage 2-3 period is unique and that no other cutoffs exist at different locations. To this end, we performed placebo tests, with P-values, regression coefficients, and 95% confidence intervals for different cutoff selections shown in Figure 9 [Figure 9: see original paper]:

Figure 9 Placebo Tests for Different Cutoffs in Stages 2 and 3

Figure 9-A assumes four alternative cutoff locations. Notably, among the four placebo cutoffs (pseudo-cutoffs), three have P-values significantly greater than 0.05, indicating no treatment effects at these points. Although the fourth cutoff's regression coefficient P-value is below 0.05, its effect is weaker than the selected cutoff, reaffirming that the chosen cutoff genuinely exists with significant effects.

In summary, local and global regression results demonstrate that at the Stage 2-3 transition point (April 28), COVID-19 containment policies implemented in Stage 2 indeed caused a significant rebound in public sentiment values among Weibo users, with the increase ranging from 0.06–0.08 units.

3.3 BERTopic Topic Modeling Analysis

The previous section confirmed through regression discontinuity in time that different COVID-19 containment policies implemented in Stages 1 and 2 had significant causal impacts on the decline in Weibo users' sentiment on February

20 and the rebound on April 28. However, these analyses could not further reveal the specific hot comment content driving sentiment fluctuations. This section employs BERTopic topic modeling to identify fifteen hot topics from the 310,000 Weibo user comment texts obtained in Section 2.1 (Table 12), then conducts discontinuity regression analysis on these identified hot topics (Figures 10 [Figure 10: see original paper]–13 [Figure 13: see original paper]) to explore changes in each topic across stage transition points. This approach constructs a causal logic chain from COVID-19 containment policy implementation → user comment hot topics → sentiment fluctuations, revealing the underlying reasons for policy impacts on Weibo users' sentiment.

Table 12 Fifteen Hot Topics Identified by BERTopic Topic Modeling

Following the regression discontinuity analysis steps outlined in Section 3.2, we conducted discontinuity regression analysis on the top four hot topics identified by BERTopic at the three stage transition points. Results are shown in Figure 10 [Figure 10: see original paper], where the horizontal axis represents time, the vertical axis represents the natural logarithm of topic frequency (characterizing topic changes over time), D denotes the discontinuity effect value, and P indicates the statistical significance of the cutoff treatment effect. Figures 10-A/B/C reveal that although Topic 2 (Cheering for Wuhan), Topic 5 (New Confirmed Cases by Region), and Topic 12 (Beijing Epidemic Information) rank among the top three most-discussed topics on Weibo, they show no significant discontinuity effects at the Stage 1-2 or Stage 2-3 transitions ($P > 0.05$), suggesting these three topic categories are not primary drivers of Weibo users' emotional fluctuations.

Topic 18 (School Closure and Lockdown) represents the fourth most-discussed topic among Weibo users. Figure 10-D shows that Topic 18 exhibits a significant discontinuity effect at the transition between Stage 2 (containment and recovery) and Stage 3 (normalized prevention and control) ($p = 0.0067 < 0.01$, $D = -0.4491$), reflecting a significant decline in discussion frequency regarding school closures and lockdowns at the Stage 2-3 transition. Combined with the fact that public sentiment values show a significant upward shift from Stage 2 to Stage 3, we can conclude that school reopening constitutes a primary reason for the public sentiment rebound at the Stage 2-3 cutoff.

Figure 11 shows discontinuity regression analysis results for Topics 20, 19, 23, and 27.

Further analysis of Topics 23 (Discussing Lockdown Costs) and 27 (Transportation Shutdown Controls)—both closely related to government containment policies—reveals that Topic 23 exhibits a significant discontinuity effect at the Stage 1-2 transition ($p = 0.0125 < 0.05$, $D = 0.4876$), indicating increased discussion frequency about lockdown costs. Combined with the significant sentiment decline at this transition, we infer that strict lockdown measures primarily caused the public sentiment drop. Topic 20 (Discussing Virus Origins) also shows a significant discontinuity effect at the Stage 1-2 transition

($p=0.0013<0.01$, $D=0.8609$), suggesting that growing attention to virus origins contributed to sentiment decline. Topic 19 (Celebrating Medical Workers' Triumphant Return) shows a significant discontinuity effect at the Stage 2-3 transition ($p=0.0338<0.05$, $D=0.5636$), indicating that discussions about medical staff departing Wuhan contributed to sentiment rebound.

Figure 12 shows analysis results for Topics 33, 38, 41, and 45.

Topic 38 (Improving Epidemic Situation) demonstrates a significant discontinuity effect at the Stage 2-3 transition ($p=0.0382<0.05$, $D=0.3536$), with increased discussion frequency about China's overall improving epidemic situation contributing to sentiment rebound.

Figure 13 shows analysis results for Topics 46, 56, and 64.

These topics show no significant discontinuity effects at either transition ($P>0.05$), indicating they are not primary drivers of sentiment fluctuations.

Based on the comprehensive analysis results from Figures 10–13, we constructed a causal chain illustrating how COVID-19 containment policy implementation affects Weibo users' sentiment fluctuations, as shown in Figure 14 [Figure 14: see original paper]:

Figure 14 Causal Chain of COVID-19 Containment Policy Impact on Weibo Users' Cognition and Sentiment

Based on the comprehensive analysis of semantic and emotional causal inference from over 310,000 public user comments on COVID-19 posted under 12 government, news media, and well-known blogger accounts on Sina Weibo in 2020, we can draw the following conclusions:

First, the implementation of COVID-19 containment policy combinations exerted clear discontinuity effects on sentiment fluctuations among Sina Weibo users. This impact caused a significant decline in public sentiment values among Weibo users by 0.07–0.12 units around February 20, 2020, and a significant rebound of 0.06–0.08 units around April 28, 2020. The implementation of COVID-19 containment policies triggered netizen comments on Weibo, which subsequently converged into hot topics. These discussed topics shaped identification among more Weibo users, thereby creating group linkage effects from cognition to emotional levels.

Second, the COVID-19 containment policy combinations exhibited heterogeneous impacts on Weibo users' cognition and sentiment. Upon individual examination, only four of the eight policies triggered the formation of hot discussion topics during implementation, possibly because these policies involved everyone and featured coercive measures. Among these individual policies, only school closure policy implementation sparked heated discussion and significantly impacted public sentiment during the Stage 2 to Stage 3 transition, reflecting that individual policy implementation has limited influence on Weibo users' cognition and emotions. Additionally, Topic 23 (Discussing Lockdown Costs)

emerged as the reason for the significant decline in public sentiment from Stage 1 to Stage 2, indicating that the inconvenience brought by containment policy combinations to the public received heated discussion from Weibo users and significantly influenced downward group sentiment fluctuations.

Third, tracing the fluctuations in Weibo users' sentiment reveals influences from both COVID-19 containment policy combinations and other spontaneously discussed hot topics among the public. For instance, hot topics that significantly affected user sentiment changes at the two stage transition cutoffs, such as Topic 20 (Discussing Virus Origins) and Topic 19 (Celebrating Medical Workers' Triumphant Return), were clearly unrelated to policy implementation. This further corroborates that applying regression discontinuity in time and BERTopic topic modeling algorithms to analyze user sentiment changes triggered by hot topic linkages can achieve retrospective inference effects.

4 Conclusion and Outlook

The covert transmission and uncertain development characteristics of COVID-19 pose unprecedented challenges for epidemic prevention and control, and effective pandemic response cannot succeed without means to quasi-real-time monitor policy impacts. Grounded in the Emotions as Social Information theory, this study proposes a novel method for mid-implementation monitoring and evaluation of epidemic prevention policies that integrates the BERTopic topic model with Multiple Linear Regression (MLR) and Regression Discontinuity in Time (RDiT). Analysis of over 310,000 high-frequency COVID-19-related user comments from Sina Weibo in 2020 reveals that: (1) The implementation of COVID-19 containment policy combinations caused a significant decline in public sentiment values among Weibo users by 0.07–0.12 units around February 20, 2020, and a significant rebound of 0.06–0.08 units around April 28, 2020; (2) The policy combinations exhibited heterogeneous impacts on users' cognition and sentiment, with policies involving individuals and featuring coercive measures more likely to trigger heated online discussions and significantly depress public sentiment; (3) The causal chain of policy intervention → user hot topics → sentiment fluctuations constructed through this analysis enables retrospective inference of policy implementation effectiveness.

The theoretical contributions of this paper are twofold: (1) It provides new perspectives for big data-driven evidence-based decision-making in public health policy. Existing research indicates that big data analytics drives theoretical development through diverse pathways, including big data-driven theoretical framework construction, refined validation of existing theories, fine-grained theoretical elaboration and precise prediction, and theory generation revealing new phenomena [23]. The framework constructed in this study based on systems perspective for analyzing COVID-19 prevention policy impacts on social media users, along with the approach of discovering public pandemic cognition hotspots and inferring policy impacts on public sentiment through social media comment analysis, represents both a more nuanced test of existing theories

and provides a bridging connection between macro-level policy interventions and micro-level user cognition, facilitating theoretical elaboration and analysis at different granularities. (2) It offers new empirical examples for causal inference in policy evaluation based on textual data. In recent years, as causal inference models have been applied in evidence-based public policy decision-making, the Potential Outcomes Model (POM) has unified experimental and observational research within a single framework, promoting interdisciplinary integration between statistics and public policy evaluation research [24]. The regression discontinuity in time applied in this study represents a typical potential outcomes model. The analytical application demonstrates that this method can be used for policy intervention impact analysis in public policy evaluation, effectively addressing causal inference questions in policy assessment, particularly retrospective inference issues with textual data, thereby providing new cognitive perspectives and investigative methods for deeply understanding how policy implementation triggers emotional fluctuations among internet users.

The practical value of this study primarily lies in proposing a novel method for mid-implementation monitoring and evaluation of public health emergency prevention policies characterized by direct public engagement, data-driven insights, and retrospective inference capabilities, providing new tools for improving multi-channel pandemic monitoring and early warning systems and implementing scientifically precise epidemic prevention. Furthermore, the method proposed in this paper demonstrates strong potential applicability. Beyond its exemplification in quasi-real-time monitoring of public health policies, it can also be applied to other policy evaluation domains that affect the populace and require timely acquisition of public policy responses, further promoting the extension of policy evaluation from pre-assessment and post-evaluation to real-time mid-implementation tracking.

This paper also has several limitations. First, the study primarily focuses on central-level containment policies, treating national epidemic prevention and control as a unified whole, thereby somewhat overlooking heterogeneity across provinces and regions. Second, constrained by various factors, the study's data timeframe concentrates on the first year of the COVID-19 outbreak (2020). Future research could incorporate more recent data to examine how epidemic prevention policies differently affect netizens' psychological cognition and emotional fluctuations under continued pandemic volatility.

Footnotes:

<https://m.weibo.cn/1642909335/4613864249365413>

February 20 was selected as the cutoff because epidemic prevention and control entered a full containment phase thereafter

April 28 was selected as the cutoff because epidemic prevention and control entered a normalized phase thereafter

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Author Contributions

Wu Jun: Proposed research topic and ideas, designed experimental framework, wrote initial draft and revised final manuscript

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Note: Figure translations are in progress. See original paper for figures.

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