Impact assessment of vaccine-related negative news and incentive measures on vaccine hesitancy in Hong Kong

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Abstract

Vaccine hesitancy underscores the critical need to quantify the influence of diverse factors on vaccine uptake. In this study, we develop a social-epidemiological transmission model with an imitation mechanism to characterize the interactions between social and epidemiological dynamics. We introduce a risk score to the payoff function to assess vaccine-related negative news and incentive measures' impacts on COVID-19 vaccine uptake during the pandemic. By fitting our model with the real data in Hong Kong, we reveal that the vaccine-related negative news drastically impeded vaccination efforts. Scenario analyses suggest that, without incentive measures, the projected fifth wave of COVID-19 in Hong Kong would have infected 98% of the population, resulting in an estimated 51,752 deaths. Both the model simulation and the real data demonstrate that the incentive measures have successfully encouraged vaccine uptake and saved approximately 38,419 lives. However, we found that the willingness to take vaccines quickly declined after the incentive measures were finished, implying limited benefits in mitigating the effect of negative news in the long run. This study also highlights the need for booster doses in the face of the immune escape of the Omicron variants. Our model offers data-driven

insights into the interplay between negative news, vaccine hesitancy, and incentive measures, shedding light on the effective preparation for emerging infectious disease outbreaks.

Keywords: vaccine hesitancy; negative news; incentive measures; COVID-19

Introduction

Vaccine hesitancy has been among the top ten global health threats identified by the World Health Organization (WHO)[1]. The ongoing mutations of COVID-19 highlight the need to address vaccine hesitancy, as it can lead to repeated infections and elevate the risk of developing Long COVID[2,3]. Vaccine hesitancy extends beyond COVID-19. Recent WHO statistics indicate that vaccination coverage rates for measles, diphtheria-tetanus-pertussis (DTP), and human papillomavirus (HPV) fall short of established targets[4]. This reluctance to vaccinate undermines the United Nations' Sustainable Development Goal (SDG) of healthy lives and well-being for all at all ages[5]. Addressing vaccine hesitancy is essential for achieving better health outcomes globally.

The factors contributing to vaccine hesitancy can be grouped into three main categories: individual and interpersonal, vaccine-specific, and contextual factors[6]. Individual factors include physical health[7], vaccination history[8,9], trust in government and institutions[10], societal demographics[11], risk perception, and awareness[12]. In addition, daily interactions and living environments influence people's willingness to receive vaccinations[13,14]. Vaccine-specific factors encompass concerns regarding side effects[15,16], the effectiveness of vaccines[17,18], and the perceived importance of vaccination[19]. In today's information-driven society, contextual factors such as conspiracy theories[20] and misinformation[21,22] play a crucial role in vaccine hesitancy and must be addressed[23].

Negative news about vaccines often focuses on safety concerns, a leading cause of vaccine hesitancy[16,17,24]. The historical misuse of medical and vaccine research during the colonial era in Africa continues to affect COVID-19 vaccination rates on the continent[25]. Negative news has far stronger effects on public trust than positive news, often resulting in high engagement[26–28] and the proliferation of conspiracy theories and misinformation. It has been found that right-wing or conservatives exhibit relatively higher levels of vaccine hesitancy and are more susceptible to conspiracy theories and misinformation[21,29–35]. Consequently, the governance of right-wing parties or the claim of prominent anti-vaccine activists can further exacerbate vaccine hesitancy. Furthermore, misinformation contributes to public noncompliance with health guidelines and spreads vaccine hesitancy[36]. Thus, strengthening trust in reliable sources is vital to counteract the detrimental effects of misinformation. Additionally, various incentive measures have been tried globally to improve vaccine uptake, though with varying success. In Europe, cash incentives were effective in boosting vaccination rates[37]. Interestingly, smaller cash rewards positively affected vaccination rates more than higher cash rewards[38]. However, several studies have shown that negative news regarding the Oxford AstraZeneca vaccine did not affect its uptake in the UK and Denmark[39–41], and economic incentives did not increase overall vaccination rates at all in the United States[42,43]. Additionally, a previous study has indicated that in Hong Kong, the incentive measures have little impact on encouraging older adults to get vaccinated[44].

The COVID-19 epidemic in Hong Kong provides an ideal case study, offering a real-life experimental setting to assess the impact of vaccine-related events on vaccine hesitancy. During the pandemic, the public willingness to get vaccinated declined due to vaccine-related negative news, including packaging defects, serious adverse events after vaccination, and limited information about deaths possibly linked to vaccination[45–47]. Subsequently, various incentive measures were introduced, including material gifts, economic rewards, and vaccination leave[48]. While many surveys have examined the effects of various factors on vaccine hesitancy in Hong Kong[49–53], predefined surveys often fail to capture all relevant factors and events, and limited sample sizes often lead to selection bias. Thus, understanding these vaccine-related events is crucial for addressing vaccine hesitancy effectively.

In this study, we aim to leverage real epidemiological data to assess the impact of vaccine-related negative news and incentive measures on vaccine hesitancy in Hong Kong. We develop a social-epidemiological model to account for key events affecting vaccine uptake. With this model, we conduct scenario analyses to evaluate how these elements affect the number of infections and deaths.

Results

The dynamic of control measures and COVID-19 variants in Hong Kong

COVID-19, as an RNA virus, shows high variability, evolving from the original wild type into thousands of lineages with different levels of infectivity and mortality risk[54]. To better fit the outbreak dynamics, we focused on the variants of concern (VOCs) circulated in Hong Kong, as identified by the WHO. By analyzing the submitted genetic sequences, we estimated the monthly proportions of different VOCs to illustrate the dynamics of COVID-19 variants throughout the study period (**Error! Reference source not found.**A).

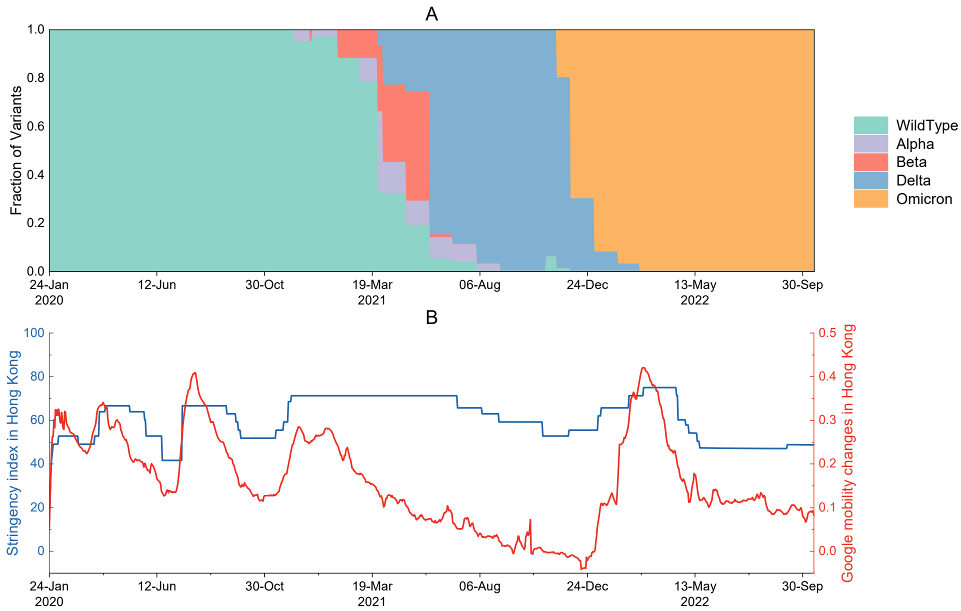

Fig. 1. A: The dynamic of different COVID-19 variants in Hong Kong from January 24, 2020, to October 15, 2022. B: The dynamic of stringency index and mobility in Hong Kong during the same period.

As of October 15, 2022, Hong Kong has experienced five waves of COVID-19. The government consistently implemented timely intervention measures to control each wave's outbreak. The stringency index, which includes containment and closure policies, such as lockdown policies[55], substantially affected citizen mobility, as tracked by mobile phone applications[56,57]. Before the end of 2020, Google Mobility changes generally aligned with the stringency index. While the stringency index stayed high, Google Mobility showed a decreasing trend from early 2021 to the end of July 2021 (**Error! Reference source not found.**B), which indicated that the emergence of pandemic fatigue may potentially reduce the effectiveness of public health and social measures (PHSMs)[58].

Before the vaccination program began, PHSMs effectively contained the first four waves of outbreaks (Fig. 2). Since the vaccination program started, negative news about vaccines led to decreased public willingness to be vaccinated, slowing the progress of vaccination rates (Fig. 3B and C). In response, the Hong Kong government and local private sectors introduced various incentive measures to encourage more people to get vaccinated (Fig. 3C). Nevertheless, when the Omicron variant arrived in Hong Kong in November 2022, the lack of sufficient herd immunity and less effective PHSMs proved inadequate (Fig. 3D-F). The fifth wave (December 31, 2021, to January 29, 2023) claimed 13120 deaths compared to 213 in the first four waves) in Hong Kong[59]. Most of the fatalities could have been saved if the vaccination coverage was wider[60].

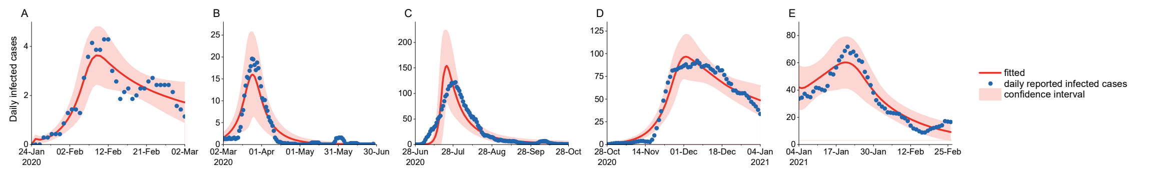

Fig. 2. The transmission dynamics of COVID-19 in Hong Kong during the pre-vaccination phase (January 23, 2020, to February 26, 2021). The A-E periods represent four waves of the epidemic observed in this timeframe. The curves and shaded regions show the fitted daily infection dynamics, while the data points indicate the daily infection numbers reported by the Hong Kong government.

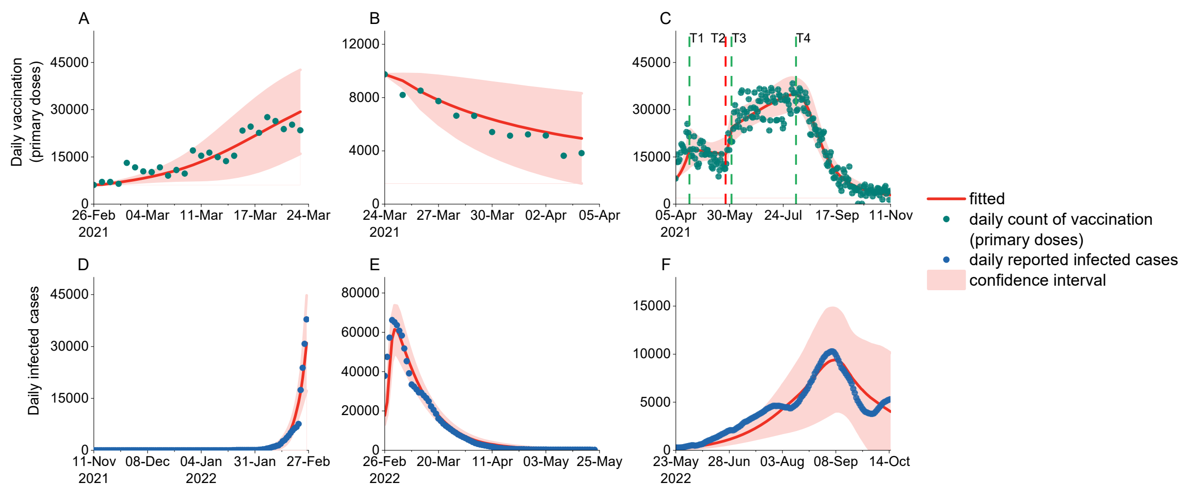

Fig. 3. The dynamic of COVID-19 daily vaccination during the first two primary doses phase (A-C, February 26, 2021, to November 10, 2021, when the first two doses were being administrated) and transmission dynamic of COVID-19 during the booster doses phase (D-F, November 11, 2021, to October 15, 2022) in Hong Kong. The red curves and shaded regions show fitted data and a 95% confidence interval. The blue and dark green dots represent the newly infected cases and the number of newly administrated vaccinations reported daily. In panel C, T1 to T4 represent events related to vaccines. T1 represents serious adverse events after vaccination. T2 shows the initiation of incentive measures by the government and local private sectors. T3 represents limited information about deaths possibly linked to vaccination. T4 shows the end of the incentive measures. The green and red dash represent falling and rising vaccine willingness, respectively.

The adverse impact of negative news and the short-lived effect of incentive measures on vaccine uptake

To assess the impact of vaccine-related events on vaccine uptake in Hong Kong, we used Markov Chain Monte Carlo (MCMC) to fit our model since the vaccination program started in Hong Kong. We quantified the risk score in payoff terms to assess how different events influenced people's willingness to get vaccinated.

Several vaccine-related events were identified, including negative news and incentive measures (see the Methods for more details). The vaccine packaging defects, the serious adverse events after vaccination, and limited information about deaths possibly linked to vaccination increased the vaccine hesitancy of the public (Table 1). Notably, the impact of the vaccine packaging defects on vaccination willingness exceeds that of the other two events. In response to a slow vaccine rollout, the Hong Kong government and local private sectors introduced several incentive measures to encourage vaccination including lucky draws and cash bounties, which increased the benefits of receiving primary vaccine doses (Table 1). However, their effect was temporary and would end when these reward programs concluded (as shown by the red curve in **Error! Reference source not found.**B).

Table 1. The impact of different events on the payoff of vaccine uptake.

Event times	Events	Potential factors	Payoff changes for the first two primary doses	Payoff changes for booster doses
2021.03.24	Vaccine packaging defects	Vaccine-specific[46,59], government credibility[46,60]	-99.35	-

2021.04.19	Serious adverse events after vaccination	Government credibility[61], vaccine-specific[61], misinformation[46]	-66.08	-
2021.05.26	Government and business incentive measures	Incentive measures	74.48	-
2021.06.01	Limited information about deaths possibly linked to vaccination	Government credibility[46,62,63], misinformation[46,62,64]	-65.59	-
2021.08.09	End of the incentive measures	Incentive measures	-58.57	-

To assess these negative news and incentive measures' impacts on epidemic dynamics, we simulated the daily infection and vaccination rates under various scenarios with and without negative news and incentive measures, respectively: (a) fitted curve of the actual scenario (with both negative news and incentive measures; the red curve in **Error! Reference source not found.** and**Error! Reference source not found.**); (b) the scenario with negative news but without incentive measures (the yellow curve in **Error! Reference source not found.** and**Error! Reference source not found.**); (c) the scenario with neither negative news nor incentive measures (the teal curve in **Error! Reference source not found.** and**Error! Reference source not found.**); (d) the scenario without negative news but with incentive measures (the purple curve in **Error! Reference source not found.** and**Error! Reference source not found.**).

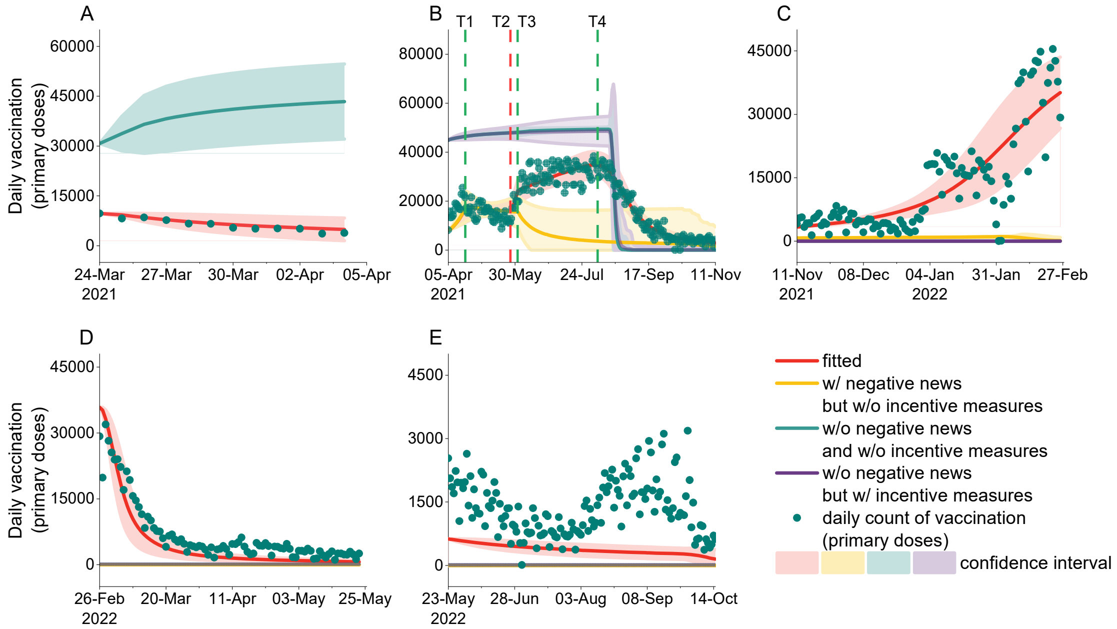

Fig. 4. Daily vaccine uptake over time (primary doses). The time frame ranges from the onset of the vaccine packaging defects until October 15, 2022. The solid curves and bands represent the mean of fitted or simulated results, and 95% confidence intervals, respectively. The red curves and dark green dots denote the fitted and actual daily vaccination numbers, respectively. With negative news but without incentive measures, without negative news plus incentive measures, and with negative news but with incentive measures, the simulated results are represented in yellow, teal, and purple, respectively.

Comparing scenario (b) with the actual scenario (a), we found that, without any incentive measures, the daily vaccine uptake could be much lower than that of the real scenario (**Error! Reference source not found.**B-E). Upon the arrival of the Omicron variant, the epidemic would peak earlier than anticipated, with peak daily infections reaching 3.55 times the actual peak (**Error! Reference source not found.**C). By October 15, 2022, the introduction of incentive measures is estimated to have saved approximately 38,419 lives. Without the negative news, daily vaccinations would continue to rise until reaching maximum capacity and remain steady until mid-August, achieving the first primary doses vaccination rate of 99.22% by August 19, 2021—92.06% higher than actual figures (**Error! Reference source not found.**A and B).

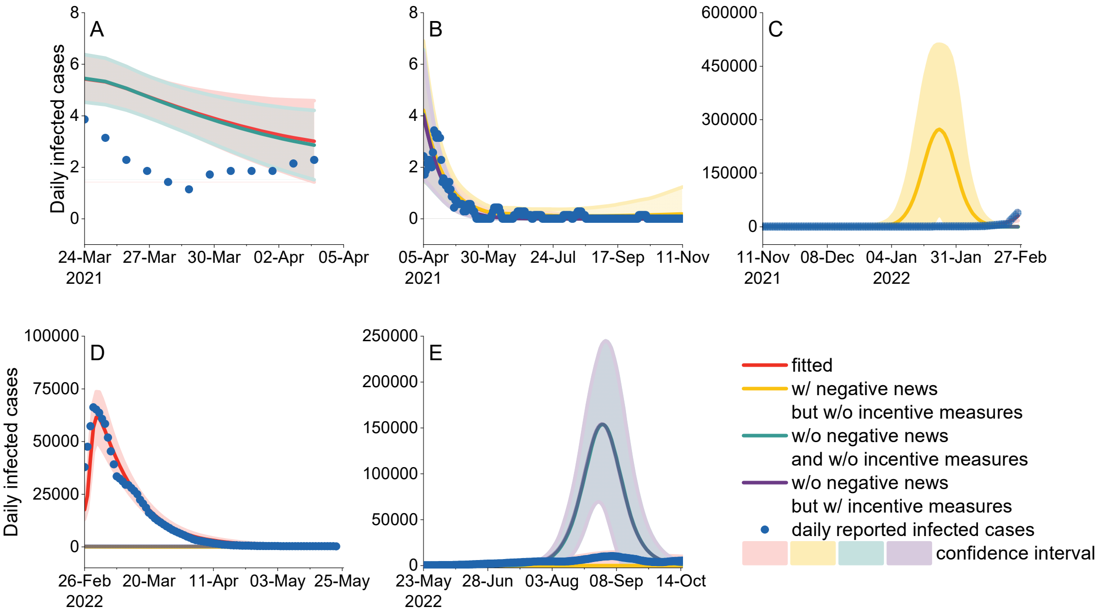

Fig. 5. Daily infected infections over time. The time frame ranges from the onset of the vaccine packaging defects until October 15, 2022. The solid curves and bands represent the mean of fitted or simulated results, and 95% confidence intervals, respectively. The red curves and blue dots denote the fitted and actual daily infections, respectively. With negative news but without incentive measures, without negative news plus incentive measures, and with negative news but with incentive measures, the simulated results are represented in yellow, teal, and purple, respectively.

Additionally, in both the scenarios without negative news (c and d), the daily vaccine uptake shared a similar pattern regardless of the incentive measures (as shown by the overlapping flat teal and purple curves in **Error! Reference source not found.**B). With universal primary vaccination doses, the Omicron wave in mid-January 2022 would be averted, substantially reducing infection and mortality rates (**Error! Reference source not found.**D). However, by late August 2022, a new more serious wave of outbreaks would emerge caused by the Omicron mutant strain sub-lineages BA.4/BA.5 (**Error! Reference source not found.**E). In this scenario analysis, the projected cumulative number of infections by October 15, 2022, was approximately 6.18 million, which was 2.39 million more than the fitted actual figure. Despite the increase in infected cases, an estimated 5,549 lives would be saved.

The synergistic effect of introducing incentive measures and mitigating negative news

We simulated scenarios with and without incentive measures to examine how the proper mitigation of negative news may affect the daily infection and vaccination rates. The scenarios included: (a) mitigating 75%, 50%, and 25% of the impact of negative news without incentive measures, respectively; (b) mitigating 15%, 10%, and 5% of the impact of negative news with incentive measures, respectively (since incentive measures can compensate for 56.6% of the impact of negative news, shown in Table 1). We found that without incentive measures, the government must mitigate at least 50% of the negative news impact to achieve a high (87.6%) coverage of the population receiving primary doses by November 11, 2021. As a result, the fifth wave of outbreak (in early 2022) could have been prevented (Fig. 6A and B, Fig. 7A). Introducing incentive measures could effectively reduce vaccine hesitancy so that as little as 5% negative news mitigation is sufficient to prevent the fifth outbreak (Fig. 6D and E, Fig. 7C). However, merely increasing the vaccination rate of the two primary doses is insufficient to prevent the future outbreak due to the immune escape of the Omicron variants and the low booster dose vaccine uptake (Fig. 6C and F).

We simulated how the incentive measures for booster doses to contain the future outbreak. The results showed that if small- to medium-level incentive measures were introduced for booster doses after the primary doses vaccination program, the future Omicron-led outbreak could be curbed, potentially reducing infections by 6.14 million and saving 4,487 lives by October 15, 2020, compared with a scenario without any incentive measures for booster doses (Fig. 8).

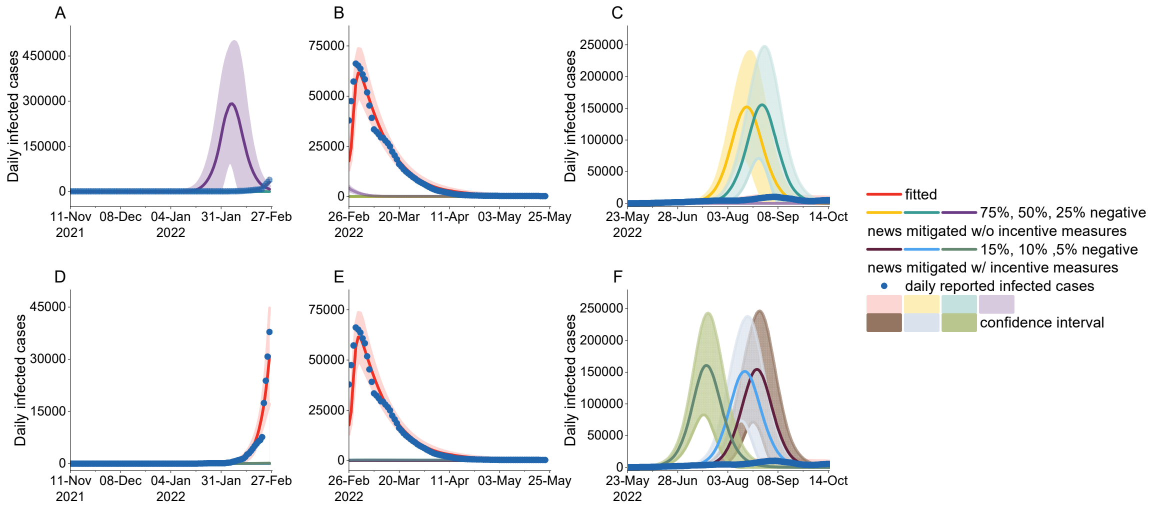

Fig. 6. Daily infected infections over time. The time frame ranges from the start of the booster dose until October 15, 2022. The solid curves and bands represent the mean of fitted or simulated results, and 95% confidence intervals, respectively. The red curves and blue dots denote the fitted and actual daily infections, respectively. Mitigating the impact of negative news by 75%, 50%, and 25% without incentive measures, the simulated results are represented in yellow, teal, and purple, respectively. Mitigating the impact of negative news by 15%, 10%, and 5% with incentive measures, the simulated results are represented in dark brown, light blue, and dark green, respectively.

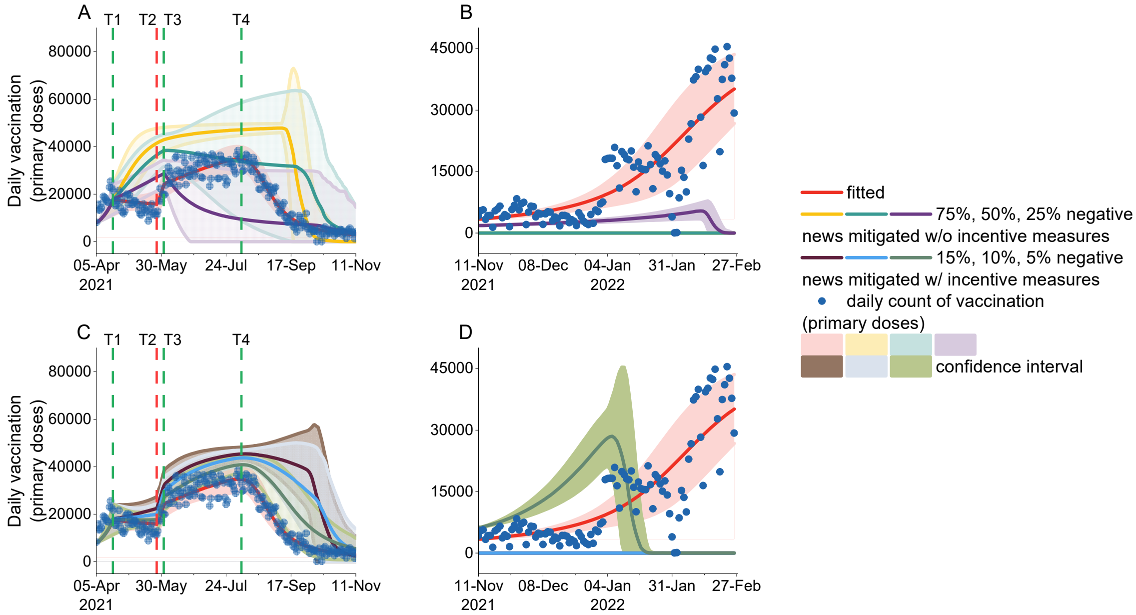

Fig. 7. Daily vaccine uptake over time (primary doses). The time frame ranges from the recovery of vaccination until February 26, 2022. The solid curves and bands represent the mean of fitted or simulated results, and 95% confidence intervals, respectively. The red curves and blue dots denote the fitted and actual daily vaccination numbers, respectively. Mitigating the impact of negative news by 75%, 50%, and 25% without incentive measures, the simulated results are represented in yellow, teal, and purple, respectively. Mitigating the impact of negative news by 15%, 10%, and 5% with incentive measures, the simulated results are represented in dark brown, light blue, and dark green, respectively.

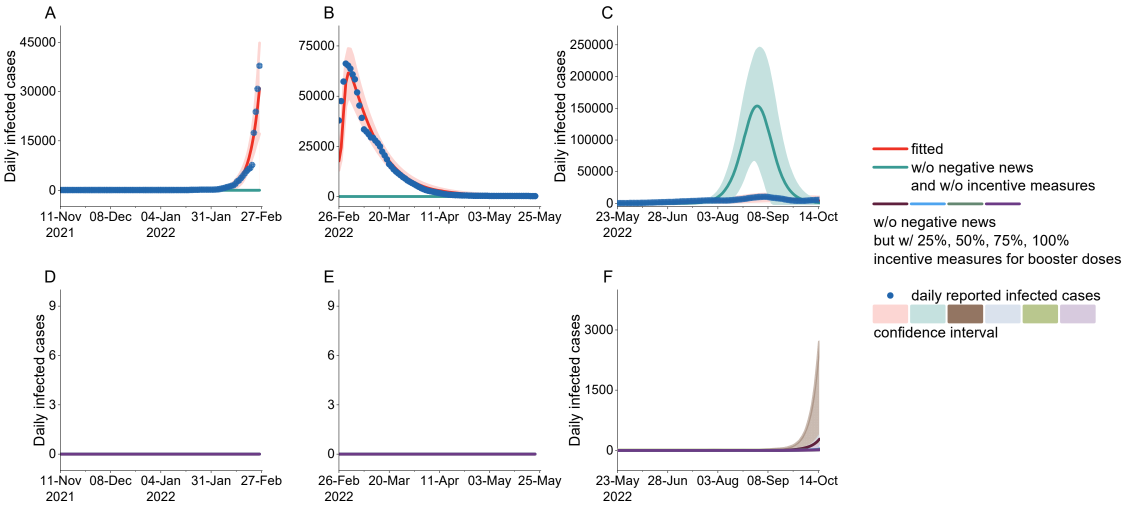

Fig. 8. Daily infected infections over time. The time frame ranges from the start of the booster dose until October 15, 2022. The solid curves and bands represent the mean of fitted or simulated results, and 95% confidence intervals, respectively. The red curves and blue dots denote the fitted and actual daily infections, respectively. The scenario (without negative news and without incentive measures) is shown in teal. Without negative news but providing 25%, 50%, 75%, and 100% incentive measures effectiveness for booster dose, the simulated results are represented in dark brown, light blue, dark green, and purple, respectively.

Discussion

In our study, we fit real epidemic dynamic data to understand how vaccine-related events influenced vaccine uptake in Hong Kong. Our research offers evidence and insights, highlighting the positive synergistic effect of managing negative news and introducing incentive measures to achieve herd immunity. We recommend that only modest incentive measures for booster doses are sufficient to control outbreaks caused by immune escape.

This study provides data-driven evidence for previous survey studies[50–52,65], assessing the importance of specific vaccine-related events, including the impact of negative news and incentive measures on vaccine uptake. Negative news has been proven to attract more attention and has a greater impact than positive news[26–28,66]. Vaccine safety is a primary concern across all age groups in Hong Kong[50]. Unlike other measures targeting specific groups, mitigating the impact of negative news can accelerate the achievement of herd immunity more effectively. We found that only reporting limited information about deaths possibly linked to vaccination can increase vaccine hesitancy, which is likely due to a lack of trust in the government and the spread of misinformation and rumors. Previous research has shown that providing information about vaccine risks does not influence willingness to vaccinate[67]. Our results suggest that the timely, proper, and transparent publicity of pandemic and vaccine safety-related information could boost vaccination rates by mitigating misinformation originating from negative news. Our findings show that incentive measures can boost vaccine uptake, but their effects are short-lived, and vaccine hesitancy remains slightly reduced after the incentive measures end. Mitigating the effects of negative news by 50% can achieve high coverage of the first two primary doses and save costs on incentive measures, allowing resources to be reallocated toward increasing vaccine supply, expanding healthcare capacity, and supporting economic growth. Ultimately, it will aid in the faster achievement of herd immunity and minimize unnecessary infections and deaths.

Our results shed light on the fact that even with high vaccine coverage of first primary doses, neglecting booster doses could lead to a stronger outbreak of Omicron in Hong Kong. The principle underlying the outbreak is the accumulation of susceptible individuals and the relaxation of PHSMs, which aligns with our previous research on respiratory infectious diseases[68,69]. Thus, when addressing future virus spread and vaccine promotion, the government should not only focus on current transmission dynamics but also consider virus characteristics to develop seamless and comprehensive strategies. Fortunately, we observed that minimal incentive measures for booster doses can prevent this outbreak. The synergistic effect of combining incentive measures and negative news mitigation indicates a cost-effective approach to promoting vaccination programs during an epidemic.

Our research has limitations. First, our study’s timeframe was limited to data available up to October 15, 2022, due to the availability of Google Mobility data. It is important to identify alternative public human mobility data for future epidemic surveillance and modeling. Second, this study did not explore how negative news and incentive measures affect different socioeconomic groups. A study has indicated that in Hong Kong, incentive measures have little impact on encouraging older adults to get vaccinated[44].

Our model is flexible and can be easily extended to account for the composition of different subpopulations, aiding the formulation of more targeted policy measures. It is important to explore age-specific responses to these key events given representative survey data. Third, our study focused on data from Hong Kong. To expand our research to other regions, we would require relevant epidemic data and event information from each area. However, some regions lack available data, which limits our study to Hong Kong. Nonetheless, our model can be easily adjusted to evaluate vaccine-related events in different regions, helping them develop vaccination strategies suited to their specific needs.

In summary, our research assessed the effects of negative news and incentive measures on vaccine willingness during the COVID-19 crisis. We highlighted the importance of mitigating the impact of negative news and the positive effect of incentive measures on increasing vaccine uptake. Our model can be adapted to various national and regional contexts, making it a valuable tool for evaluating certain events. It also offers scalability to address future outbreaks, providing the government with valuable insights to effectively promote vaccines in response to different viral threats.

Methods

Data Source

We obtained the number of daily reported infected cases from January 24, 2020, to October 15, 2022, and the daily vaccination counts from February 26, 2021, to October 15, 2022, from the DATA.GOV.HK database[70]. We combined five types of cases (epidemiologically linked with local case, epidemiologically linked with possibly local case, local case, locally acquired case, and possibly local case) into a single category of local cases and applied a 7-day moving average for analysis. For vaccination data, we assumed that the Sinovac and BioNTech vaccines have the same efficacy, so we merged the numbers of people vaccinated with these two vaccines. The contact matrix in Hong Kong was projected using empirical data from the COVID-19 era[71]. Additionally, we collected daily Google and Apple mobility data during the study period[56,57]. We used the average changes in "retail_and_recreation_percent_change_from_baseline" and "transit_stations_percent_change_from_baseline" from Google mobility data to represent the impact of PHSMs on population mobility. The Apple data includes mobility data for "driving" and "walking". Since Google data has missing data for the period from January 24, 2020, to February 14, 2020, we estimated the missing Google mobility data using Apple mobility data as follows:

$$GM_{\tau} = AM_{\tau} + diff_{-\tau} + U(-1,1)$$

where GM represents the impact of PHSMs on population mobility, and AM represents the average of "driving" and "walking". The first COVID-19 wave in Hong Kong occurred from January 24, 2020, to March 1, 2020. Here, τ represents the time of missing Google data, i.e., from January 24, 2020, to February 14, 2020. $-\tau$ represents the first wave's remaining time, excluding the missing data period, i.e., from February 15, 2020, to March 1, 2020. $diff$ represents the difference between GM and AM during the $-\tau$ period, and $U(-1,1)$ represents a uniform distribution from -1 to 1. We used the supplemented GM data to represent the extent of mobility changes in Hong Kong under different PHSMs implementations during the epidemic.

Model Structure

We proposed a social-epidemiological transmission dynamic model based on the SEVPIRD-CT framework (susceptible, exposed, vaccinated, presymptomatic, infected, recovered, dead, contact tracing) as illustrated in SI Appendix Fig. S1. In this model, once susceptible individuals were infected, they entered an incubation period during which they were infected but not yet infectious (exposed). After the incubation period, individuals became infectious but remained asymptomatic. Some individuals would be traced by government contact tracing and isolated upon the onset of symptoms, while others would eventually move to the recovered or deceased compartments.

During the phase of vaccination programs, if susceptible individuals were vaccinated, they transitioned to a vaccinated state. When vaccinated individuals became infected, they followed the same infection state trajectory as susceptible individuals but with a lower mortality rate. Building upon this model, we utilized an imitation dynamic to simulate daily changes in the willingness to get vaccinated, expressed by the following equation:

$$\frac{dy^H}{dt} = \kappa^H y^H(1-y^H)(INC^{H_0} - INC^H + r^H_{death}(D^{H_0} - D^H) + Score_{baseline} + \sum Score_{Events})$$

where y represents the proportion of individuals vaccinated daily based on the daily maximum appointment vaccination capacity. H acts as a placeholder for the first two primary doses and booster doses, and H_0 represents the placeholder for the previous vaccine dose. κ denotes the social learning rate, while INC and D stands for the incidence rate and death rate of administering the dose H_0 or H. r is the adjustment coefficient for the difference in death rates. $Score_{Events}$ signifies the payoff gain following different events, such as vaccine packaging defects, serious adverse events after vaccination, incentive measures, etc. The sum of all terms within the last brackets is defined as risk perception, with its positivity or negativity determining the direction of individuals' willingness to get vaccinated.

Statistical Analysis

We fitted the daily reported cases for each wave of the epidemic in Hong Kong, as well as the daily number of vaccinations during the vaccination program implementation period, using MCMC methods with the MCMCstat toolbox[72]. The model parameter values for each epidemic wave are presented in SI Appendix Table 1. We randomly generated 10,000 sets of parameters using Latin Hypercube Sampling (LHS). After running all parameter sets, we selected the three sets with the most minor errors as our initial parameter sets.

We divided the Hong Kong epidemic into three stages based on the vaccination plan. The first stage was the pre-vaccination stage, from January 24, 2020, to February 25, 2021, during which the Hong Kong government relied solely on PHSMs to control the epidemic. The second stage was the initial vaccination stage, from February 26, 2021, to November 10, 2021, during which citizens could begin receiving the first two primary doses of Sinovac and BioNTech vaccines in addition to PHSMs. The third stage was the booster doses vaccination stage, from November 11, 2021, to October 15, 2022, during which citizens could start receiving booster doses of the vaccine.

For fitting each stage, we further divided each stage into segments based on the number of epidemic waves and the occurrence of certain events. For the first segment fitting, we assumed that an individual in the presymptomatic stage entered a population entirely susceptible to infection. The initial values for fitting each subsequent segment were set as the ending values of the previous segment. We used the Poisson likelihood function as the loss function for daily reported cases and vaccination numbers.

Finally, we estimated the convergence of the MCMC chains using the Gelman-Rubin diagnostic. Once the MCMC chains converged and stabilized, we randomly selected 500 parameter sets from the burn-in phase (half the chain length) to generate 95% confidence intervals based on these 500 parameter sets.

Events Screening

A previous study surveyed Hong Kong to determine reasons for vaccine hesitancy across different age groups[50]. After excluding personal factors like concerns about chronic diseases, already antibodies, and lack of social norms or support, the top three reasons were identified for each group. These reasons were then grouped into vaccine-specific issues, low trust in the government, and a lack of urgency or perceived need for vaccination. To select relevant events, we applied polynomial fitting to daily vaccination data to find inflection points in the rate changes. These were identified on April 19, May 13, June 30, July 15, August 5, October 27, and November 7, 2021. Considering the lead or lag time of events[73], related news was reviewed from the Department of Health press releases[74] and the Oriental Daily News[75] within 28 days before and after these dates. The events listed in Table 1 were then chosen, and their impact on vaccine hesitancy in Hong Kong was measured.

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