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Facemask shortage and the novel coronavirus disease (COVID-19) outbreak: Reflections on public health measures

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ABSTRACT

Background: A novel coronavirus disease (COVID-19) outbreak due to the severe respiratory syndrome coronavirus (SARS-CoV-2) infection occurred in China in late December 2019. Facemask wearing with proper hand hygiene is considered an effective measure to prevent SARS-CoV-2 transmission, but facemask wearing has become a social concern due to the global facemask shortage. China is the major facemask producer in the world, contributing to 50% of global production. However, a universal facemask wearing policy would put an enormous burden on the facemask supply.

Methods: We performed a policy review concerning facemasks using government websites and mathematical modelling shortage analyses based on data obtained from the National Health Commission (NHC), the Ministry of Industry and Information Technology (MIIT), the Centre for Disease Control and Prevention (CDC), and General Administration of Customs (GAC) of the People's Republic of China. Three scenarios with respect to wearing facemasks were considered: (1) a universal facemask wearing policy implementation in all regions of mainland China; (2) a universal facemask wearing policy implementation only in the epicentre (Hubei province, China); and (3) no implementation of a universal facemask wearing policy.

Findings: Regardless of different universal facemask wearing policy scenarios, facemask shortage would occur but eventually end during our prediction period (from 20 Jan 2020 to 30 Jun 2020). The duration of the facemask shortage described in the scenarios of a country-wide universal facemask wearing policy, a universal facemask wearing policy in the epicentre, and no universal facemask wearing policy were 132, seven, and four days, respectively. During the prediction period, the largest daily facemask shortages were predicted to be 589·5, 49·3, and 37·5 million in each of the three scenarios, respectively. In any scenario, an N95 mask shortage was predicted to occur on 24 January 2020 with a daily facemask shortage of 2·2 million.

Interpretation: Implementing a universal facemask wearing policy in the whole of China could lead to severe facemask shortage. Without effective public communication, a universal facemask wearing policy could result in societal panic and subsequently, increase the nationwide and worldwide demand for facemasks. These increased demands could cause a facemask shortage for healthcare workers and reduce the effectiveness of outbreak control in the affected regions, eventually leading to a pandemic. To fight novel infectious disease outbreaks, such as COVID-19, governments should monitor domestic facemask supplies and give priority to healthcare workers. The risk of asymptomatic transmission and facemask shortages should be carefully evaluated before introducing a universal facemask wearing policy in high-risk regions. Public health measures aimed at improving hand hygiene and effective public communication should be considered along with the facemask policy.

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Introduction

A large number of novel coronavirus disease (COVID-19) cases were initially identified in Wuhan, Hubei province, China in December 2019. The severe respiratory syndrome coronavirus (SARS-CoV-2)

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is mainly transmitted via respiratory droplets and can be transmitted between humans [1-3]. Common symptoms include fever, cough, dyspnoea, and myalgia/fatigue while less common symptoms include sputum production, headache, haemoptysis, and diarrhoea [4]. By 13 March 2020, the reported incidence of COVID-19 cases exceeded 80,000 in China of which more than 60% was in Wuhan city, and more than 80% was in Hubei province [5,6]. Globally, Thailand, Japan, South Korea, Singapore, Malaysia, France, Canada, Australia, Germany, the United Kingdom, the United States, and 111 other countries have reported COVID-19 cases.[7] Most of the confirmed cases were locally transmitted cases outside of China [7].

The World Health Organization's (WHO) guidelines concerning prevention and control of the COVID-19 outbreak recommends hand and respiratory hygiene and the use of appropriate personal protective equipment for healthcare workers in practice [8]. Patients with suspected SARS-CoV-2 infection should be offered a medical mask [8]. Regarding respiratory hygiene measures, facemask wearing with proper hand hygiene has been considered an effective measure to prevent COVID-19 transmission although WHO recommends against wearing facemasks in community settings [9,10]. Furthermore, the worldwide facemask shortage during the COVID-19 outbreak has become a social concern [11].

China is the major facemask producer in the world, contributing to 50% of the global production [12]. Normally, China can produce about 20 million facemasks per day while the productivity during the Chinese New Year holiday was lower (12 million facemasks per day) [12]. However, even if full productivity could be achieved, 20 million facemasks per day do not seem to meet the needs of a population of 1·4 billion in China under a universal facemask wearing policy. Therefore, to control the COVID-19 outbreak, the Chinese government imported more than 2·0 billion facemasks between 24 Jan 2020 and 29 Feb 2020 and extended the Chinese New Year holiday to allow for home quarantine in order to reduce the need for facemasks and other medical resources [13]. A number of factories also resumed partial productivity during the holiday by paying extra wages to their workers [14].

In this study, we simulated facemask availability during the COVID-19 outbreak using a mathematical model based on the actual development of the outbreak, public health measures introduced by the Chinese government, and national statistics on facemask production and import. We aimed to investigate the severity of the facemask shortage during the COVID-19 outbreak in China in different scenarios of facemask wearing policy and reflect on the effectiveness of this type of policy.

Methods

A cluster of COVID-19 cases was reported by the Wuhan Municipal Health Commission in late Dec 2019 [1]. The human-to-human transmission of COVID-19 was confirmed on 20 Jan 2020 by National Health Commission (NHC) of China [15]. The peak of the epidemic was estimated to be around 12 Mar 2020, and the epidemic in China has been predicted to end in late June [16,17]. The number of new cases is expected to decline after the epidemic peak, but viral transmission is still possible, and the need for facemasks will not decrease immediately. Therefore, our analysis covers the period from 20 Jan 2020 to 30 Jun 2020 (162 days in total). To simulate facemask availability in China, we used a mathematical model based on data and assumptions on the production, import, and need. Five user groups were taken into account: (1) healthcare workers; (2) infected inpatient cases, i.e., confirmed cases who are receiving treatment in hospitals; (3) suspected cases, i.e., people with respiratory symptoms; (4) observational cases, i.e., people with history of close contact with infected or suspected cases and are under medical observation; and (5) the general population. We assumed healthcare workers and infected inpatient cases need N95 facemasks while suspected and observational cases and the general population need non-N95 facemasks. We also assumed that when the N95 facemask shortage occurred, healthcare workers and infected inpatient cases would use non-N95 facemasks instead. We considered three scenarios of facemask wearing policy: (1) a universal facemask wearing policy was implemented in all regions of mainland China; (2) a universal facemask wearing policy was implemented only in the epicenter (Hubei province, China); and (3) no implementation of a universal facemask wearing policy. Universal facemask wearing policy refers to the recommendation of wearing facemasks in community settings [18].

Mathematical model

We simulated the daily facemasks availability using Eq. (1)

$$F_a(d) = F_a(d-1) + F_p(d) + F_i(d) - F_n(d), \text{ for } d = 1 \text{ to } 162 \quad (1)$$

in which *Fa(d)* is facemask availability defined as the total number of facemasks on the market and in storage at the end of day *d*. *Fa(0)* (i.e., *d = 0*) is the baseline facemask availability at the beginning of our prediction period. *Fp(d)* is the number of facemasks produced in China on day *d*. *Fi(d)* is the number of facemasks imported to China on day *d*. *Fn(d)* is the need for facemasks on day *d*.

We estimated the daily need for facemasks using Eqs. (2)–(7)

$$F_n(d) = N_{n.h} + F_{n.i}(d) + F_{n.s}(d) + F_{n.o}(d) + F_{n.g}(d) \quad (2)$$

$$N_{n.h} = \alpha(d) \times \theta \times N_h \quad (3)$$

$$F_{n.i}(d) = \beta \times N_i(d) \quad (4)$$

$$F_{n.s}(d) = \gamma \times N_s(d) \quad (5)$$

$$F_{n.o}(d) = \delta \times N_o(d) \quad (6)$$

$$F_{n.g}(d) = \varepsilon \times N_g \times P_g(d) \quad (7)$$

in which *Nn.h* is the need for facemasks for healthcare worker while *Fn.i(d)*, *Fn.s*(*d*), *Fn.o(d)* and *Fn.g*(*d*) indicate the need for facemasks for infected inpatient, suspected, and observational cases and the general population on day *d*, respectively. We set $\alpha(d)$ and θ as the need for facemasks for each healthcare workers on day *d* and the percentage of healthcare workers working on duty. We set β, γ, δ, and ε as the daily need for facemasks for each infected inpatient, suspected, and observational case, and each person among the general population, respectively. *Ng* and *Nh* are the numbers of the general population and healthcare workers, respectively. *Ni(d)*, *Ns(d)*, and *No(d)* are the numbers of infected inpatient, suspected, and observational cases on day *d*, respectively. *Pg*(*d*) is the percentage of the general population needing facemasks on day *d*.

Data source and model assumptions

Public health measures introduced by the Chinese government during the COVID-19 outbreak and the daily numbers of newly confirmed cases and deaths were summarized based on official announcements and documents from the National Health Commission (NHC), the Ministry of Industry and Information Technology (MIIT), the Centre for Disease Control and Prevention (CDC), and General Administration of Customs (GAC) of the People's Republic of China.

The parameters included in the mathematical model were estimated based on the data released by the NHC, MIIT, GAC, and CDC of the People's Republic of China or recent investigations concerning the outbreak. Model input and assumptions in our model are summarized in Table 1. Specifically, the population and numbers of active healthcare workers in mainland China and in Hubei province were obtained from China Health Statistics Yearbook 2019 [19]. We

Table 1
Parameters for estimating the facemask availability during the novel coronavirus disease (COVID-19) outbreak in China.

Parameter	Definition	Data source or assumptions	Model input
$N_{g,c}$	General population of mainland China	Data from China Health Statistics Yearbook 2019	1,395,380,000
$N_{g,h}$	General population of Hubei province, China	Data from China Health Statistics Yearbook 2019	59,170,000
$N_{h,c}$	Number of healthcare workers in mainland China	Data from China Health Statistics Yearbook 2019	12,300,325
$N_{h,h}$	Number of healthcare workers in Hubei province	Data from China Health Statistics Yearbook 2019	521,930
$N_{h,o}$	Number of healthcare workers in other regions	Data from China Health Statistics Yearbook 2019	11,778,395
$N_i(d)$	Number of infected inpatient cases in mainland China on day d	Data from National Health Commission of the People 's Republic of China	Supplementary table S1
$N_s(d)$	Number of suspected cases in mainland China on day d	Data from National Health Commission of the People 's Republic of China	Supplementary table S1
$N_o(d)$	Number of medical observation cases in mainland China on day d	Data from National Health Commission of the People 's Republic of China	Supplementary table S1
θ	Percentage of healthcare workers working on their positions	Assuming that 80% of total registered healthcare workers are working on their positions	80%
$\alpha_1(d)$	Number of facemasks need of each healthcare worker in Hubei province each day	20 Jan 2020: 2 Between 21 Jan 2020 and 12 Mar 2020 (China said peak of COVID-19 ended on 12 Mar): 10 Between 13 Mar 2020 and 30 June 2020 (Chinese medical expert predicted the end of COVID-19): 5	2 ($d = 0$) 10 ($0<d \leq 52$) 5 ($52<d \leq 162$)
$\alpha_2(d)$	Number of facemasks need of each healthcare worker in other regions each day	20 Jan 2020: 2 Between 21 Jan 2020 and 12 Mar 2020 (China said peak of COVID-19 ended on 12 Mar): 5 Between 13 Mar 2020 and 30 June 2020 (Chinese medical expert predicted the end of COVID-19): 3	2 ($d = 0$) 5 ($0<d \leq 52$) 3 ($52<d \leq 162$)
σ_1	Percentage of N95 facemasks for all the consumption of facemasks by healthcare workers in Hubei province	Assuming that 50% facemasks for all the consumption of facemasks by healthcare workers in Hubei province	50%
σ_2	Percentage of N95 facemasks for all the consumption of facemasks by healthcare workers in other regions in mainland China	Assuming that 10% N95 facemasks for all the consumption of facemasks by healthcare workers in other regions in mainland China	10%
β	Number of facemasks need of each infected inpatient case each day	Assuming that each infected inpatient case would use five facemasks each day	5
γ	Number of facemasks need of each suspected case each day	Assuming that each suspected case would use two facemasks each day	2
δ	Number of facemasks need of each medical observation case each day	Assuming that each medical observation case would use two facemasks each day	2
ε	Number of facemasks need of each general population each day	Assuming that each general population would use one facemask each day	1
$P_{g,h}(d)$	Percentage of population in Hubei province using facemasks on day d	We assume the percentage of population using facemasks as following: Between 21 Jan 2020 and 23 Jan 2020: 40% (Last working day before Spring festival holiday on 23 Jan 2020) Between 24 Jan 2020 and 9 Feb 2020: 20% (Spring festival holiday ended on 9 Feb 2020 but general people in Hubei province were required to home quarantine) Between 10 Feb 2020 and 12 Mar 2020: 40% (China announced that the peak of COVID-19 ended on 12 Mar 2020) Between 13 Mar 2020 and 30 Apr 2020: 30% Between 1 May 2020 and 30 June 2020: 20%	40% ($0<d \leq 3$) 20% ($3<d \leq 20$) 40% ($20<d \leq 52$) 30% ($52<d \leq 101$) 20% ($101<d \leq 162$)
$P_{g,o}(d)$	Percentage of population in other regions of mainland China using facemasks on day d	We assume the percentage of population using facemasks as following: Between 21 Jan 2020 and 23 Jan 2020: 40% (Last working day before Spring festival holiday on 23 Jan 2020) Between 24 Jan 2020 and 9 Feb 2020: 20% (Spring festival holiday ended on 9 Feb 2020) Between 10 Feb 2020 and 12 Mar 2020: 40% (China announced that the peak of COVID-19 ended on 12 Mar 2020) Between 13 Mar 2020 and 31 Mar 2020: 30% Between 1 Apr 2020 and 30 Apr 2020: 20% Between 1 May 2020 and 31 May 2020: 10% Between 1 June 2020 and 30 June 2020: 5%	40% ($0<d \leq 3$) 20% ($3<d \leq 20$) 40% ($20<d \leq 52$) 30% ($52<d \leq 71$) 20% ($71<d \leq 101$) 10% ($101<d \leq 132$) 5% ($132<d \leq 162$)
$F_{p,N}(d)$	Number of N95 facemasks produced in China on day d	**Estimation based on information from MIIT** Between 21 Jan 2020 and 24 Jan 2020: 600,000 Between 25 Jan 2020 and 1 Feb 2020: 107,000 Between 2 Feb 2020 and 10 Feb 2020: 417,500 Between 11 Feb 2020 and 21 Feb 2020: 728,000 Between 22 Feb 2020 and 28 Feb 2020: 919,000 Between 29 Feb 2020 and 30 Jun 2020: 1660,000	600,000 ($0<d \leq 4$) 107,000 ($4<d \leq 12$) 417,500 ($12<d \leq 21$) 728,000 ($21<d \leq 32$) 919,000 ($32<d \leq 39$) 1660,000 ($39<d \leq 162$)
$F_p(d)$	Number of total facemasks produced in China on day d	**Estimation based on information from MIIT** Between 21 Jan 2019 and 24 Jan 2020: 20,000,000 Between 25 Jan 2020 and 2 Feb 2020: 8000,000 Between 3 Feb 2020 and 10 Feb 2020: 12,000,000 Between 11 Feb 2020 and 16 Feb 2020: 18,800,000 Between 17 Feb 2020 and 21 Feb 2020: 36,85,000 Between 22 Feb 2020 and 24 Feb 2020: 54,770,000	20,000,000 ($0<d \leq 4$) 8000,000 ($4<d \leq 13$) 12,000,000 ($13<d \leq 21$) 18,800,000 ($21<d \leq 27$) 36,785,000 ($27<d \leq 32$) 54,770,000 ($32<d \leq 35$) 76,190,000 ($35<d \leq 39$) 116,000,000 ($39<d \leq 162$)

(*continued*)

Table 1 (*Continued*)

Parameter	Definition	Data source or assumptions	Model input
		Between 25 Feb 2020 and 28 Feb 2020: 76,190,000	
		Between 29 Feb 2020 and 30 Jun 2020: 116,000,000	
$F_i(d)$	Number of total facemasks imported to China on day d	**Estimation based on information from MIIT and GAC**	6000,000 ($4 \leq d \leq 9$)
		Between 24 Jan 2020 and 29 Jan 2020: 6000,000	20,000,000 ($d = 10$)
		30 Jan 2020: 20,000,000	56,166,667 ($10 < d \leq 22$)
		Between 31 Jan 2020 and 11 Feb 2020: 56,166,667	83,384,615 ($22 < d \leq 35$)
		Between 12 Feb 2020 and 24 Feb 2020: 83,384,615	40,000,000 ($35 < d \leq 40$)
		Between 25 Feb 2020 and 29 Feb 2020: 40,000,000	20,000,000 ($40 < d \leq 45$)
		Between 1 Mar 2020 and 5 Mar 2020: 20,000,000	10,000,000 ($45 < d \leq 50$)
		Between 6 Mar 2020 and 10 Mar 2020: 10,000,000	5000,000 ($50 < d \leq 55$)
		Between 11 Mar 2020 and 15 Mar 2020: 5000,000	2500,000 ($55 < d \leq 60$)
		Between 16 Mar 2020 and 20 Mar 2020: 2500,000	0 ($60 < d \leq 162$)
		Between 21 Mar 2020 and 30 Jun 2020: 0	
$F_{i.N}(d)$	Number of N95 facemasks imported to China on day d	**Assuming that 10% of import facemasks were N95 facemasks**	600,000 ($4 \leq d \leq 9$)
		$F_{i.N}(d)$=10% × $F_i(d)$	2000,000 ($d = 10$)
		Between 24 Jan 2020 and 29 Jan 2020: 600,000	5616,667 ($10 < d \leq 22$)
		30 Jan 2020: 2000,000	8338,462 ($22 < d \leq 35$)
		Between 31 Jan 2020 and 11 Feb 2020: 5616,667	4000,000 ($35 < d \leq 40$)
		Between 12 Feb 2020 and 24 Feb 2020: 8338,462	2000,000 ($40 < d \leq 45$)
		Between 25 Feb 2020 and 29 Feb 2020: 4000,000	1000,000 ($45 < d \leq 50$)
		Between 1 Mar 2020 and 5 Mar 2020: 2000,000	500,000 ($50 < d \leq 55$)
		Between 6 Mar 2020 and 10 Mar 2020: 1000,000	250,000 ($55 < d \leq 60$)
		Between 11 Mar 2020 and 15 Mar 2020: 500,000	0 ($60 < d \leq 162$)
		Between 16 Mar 2020 and 20 Mar 2020: 250,000	
		Between 21 Mar 2020 and 30 Jun 2020: 0	
$F_a(0)$	Number of facemasks available on 20 Jan 2020	Facemask storage was estimated to be seven times the daily consumption in hospitals. We assume that 70% of the facemask storage in the whole of China would be supplied to the hospital system; thus, $F_a(0) = 7 \times (\alpha_1(0) \times \theta \times N_{h.h} + \alpha_2(0) \times \theta \times N_{h.o}) / 70\% = 137,763,640 / 70\% = 196,805,200$	196,805,200
$F_{a.N}(0)$	Number of N95 facemasks available on 20 Jan 2020	Assuming 10% of Number of facemasks available were N95 facemasks $F_{a.N}(0)$=10% × $F_a(0)$=19,680,520	19,680,520

assumed that 80% of the healthcare workers would be on duty during any day of our prediction (θ). The numbers of infected inpatient, suspected, and observational cases between 20 Jan 2020 and 14 March 2020 were obtained from the NHC. Based on the clinical experience of chief physicians in China, we assumed the need for facemasks of each healthcare worker in Hubei province ($\alpha 1(d)$) and in other regions ($\alpha 2(d)$) on day d during our prediction period. We also assumed each infected inpatient, suspected, and observational case, and the general population would need five, two, two, and one facemask per day, respectively. We assumed that 50% of facemask consumption ($\sigma 1$) consisted of N95 facemasks among healthcare workers in Hubei province and 10% ($\sigma 2$) in other regions. We assumed that the percentages of general population wearing facemasks in Hubei province ($Pg.h(d)$) and in other regions of mainland China ($Pg.o(d)$) changed as the outbreak entered different stages. In our model, we assumed all facemasks on the market and in storage are available for consumption. In other words, we did not take into account factors that may limit the supply on the market, such as logistics.

MIIT estimated that China normally produces about 20 million facemasks daily. However, due to the Chinese New Year holiday and response to the outbreak, facemask productivity in early 2020 has experienced significant fluctuations. Therefore, we assumed that the daily N95 and total facemask productivity, $Fp.N(d)$ and $Fp(d)$, respectively, changed during our prediction period. According to the MIIT and GAC, China imported 2·0 billion facemasks between 24 Jan 2020 and 29 Feb 2020. The import volume in from March 2020 to the end of June was estimated based on the most recent report. We assumed that 10% of total import of facemasks were N95 facemasks. Facemask storage was estimated to be seven times the daily consumption found in hospitals [12]. We assume that 70% of the facemask storage in the whole of China would be supplied to the hospital system; thus, the baseline facemask availability, $Fa(0)$ was estimated to be 196,805,200 (assuming N95 facemasks account for 10% of total facemask storage), which was about ten times the usual daily facemask productivity in China.

Results

Fig. 1 shows the numbers of newly confirmed COVID-19 cases and deaths, public health interventions introduced by the Chinese government, and changes in facemask productivity from 31 Dec 2019 to 29 Feb 2020. The sharp increase in newly confirmed cases on 12 and 13 Feb 2020 was due to the release of the fifth version of the COVID-19 protocol in which "clinical diagnosis" was added into the diagnostic criteria of COVID-19 in Hubei province [20]. From the start of the Chinese spring festival holiday on 24 Jan 2020 until festival completion on 29 Feb 2020, daily facemask productivity increased from 8 to 116 million.

Fig. 2 shows the observed shortage and our prediction of the facemask availability (total and N95 facemasks) during the COVID-19 outbreak under different scenarios on the implementation of universal facemask wearing policy. Panic-buying and facemask price surges were reported on 20 Jan 2020 right after the confirmation of human-to-human transmission [21]. The Chinese government introduced price controls for facemasks on 25 Jan 2020 [22]. This observation indicated a facemask shortage starting as early as 20 Jan 2020, and there is no clear evidence showing the shortage has been relieved at the time of this analysis (14 Mar 2020). Our prediction model estimated the severity of the shortage between 20 Jan 2020 and 30 Jun 2020. In all of the facemask wearing policy scenarios, the shortage of N95 facemasks would occur on day 4 (24 Jan 2020) and last until the end of our prediction period (with a 2·2 million shortage), except for the period from 12 Feb 2020 to 5 Mar 2020. Specifically, in Scenario 1, assuming the universal facemask wearing policy was implemented in the whole of China, 392·6 million facemasks would have been in

short supply on day 1 (21 Jan 2020), and the shortage would end on day 132 (31 May 2020). In Scenario 2, assuming a universal facemask wearing policy was implemented in Hubei province (the epicenter), 5·3 million facemasks would have been in short supply on day 4 (24 Jan 2020), and the shortage would end on day 10 (30 Jan 2020). In Scenario 3, assuming a universal facemask wearing policy was not implemented at all, 34·6 million facemasks were in short supply on day 7 (27 Jan 2020), and the shortage would end on day 10 (30 Jan 2020). During the prediction period, the maximum daily shortages of facemasks were 589·5, 49·3, and 37·5 million in each of the three scenarios, respectively.

Discussion

In this study, we summarized the public health measures introduced by the Chinese government to relieve the facemask shortage observed during the COVID-19 outbreak and simulated the facemask availability in three scenarios of facemask wearing policy to estimate the severity of the shortage. Our findings suggest that a facemask shortage, particularly for N95 facemasks, would occur regardless of the implementation of a universal facemask wearing policy. However, the facemask shortage could be much more severe if a universal facemask wearing policy was implemented in the whole of China rather than the most severely affected areas. In addition, the shortage of N95 facemask were not alleviated under the existing public health measures.

Facemasks, especially N95 facemasks, are essential protective equipment for healthcare workers during an infectious disease outbreak [8]. Confirmed infected and suspected cases are also recommended to wear a facemask to minimize virus transmission [10]. Numerous studies have reported the effects of wearing facemasks on restricting virus transmission, such as a 3−4-fold decrease in aerosol-associated viruses and lower transmission rate among their close contacts [23,24]. Thus, maintaining a stable supply of facemasks (especially N95 facemasks) with a priority given to healthcare workers and infected people is crucial for outbreak control [25,26]. In some East Asian regions, wearing a facemask in public during flu seasons and disease outbreaks is considered a measure to constrain asymptomatic transmission in the community settings and a social responsibility norm for outbreak control, particularly after the experience of the Severe Acute Respiratory Syndrome (SARS) in 2003 [27]. However, universal facemask wearing was not recommended by WHO [28]. Previous studies found that wearing facemasks may be effective only when combined with hand hygiene, and this combined measure could reduce exposure to aerosolized influenza virus by 6-fold [18,28,29]. Therefore, to reduce transmission of respiratory viruses, a combination of public health measures is needed, for example, frequent hand-washing, wearing masks and gloves, and isolation for infected and suspected cases [9].

During the COVID-19 outbreak, in addition to the universal facemask policy, the Chinese government introduced various measures, such as lockdown of cities, shutdown of the transportation system, school closure, and hand hygiene recommendations [26,30-32]. However, implementation of these responses was not always timely, and the virus eventually spread throughout the entire country. As soon as the general population began to realize the severity of the outbreak, facemask consumption surged in only a few days, partly due to the lack of information concerning the novel virus and panic buying [18]. Under these circumstances, the Chinese government made several attempts at various efforts with respect to public communication, including updating data concerning the latest facemask productivity, release of guidelines on facemask usage, stabilizing facemask prices on the market, and offering a facemask lottery in official pathways. NHC classified each province unit into different risk levels (high-, middle-, and low-risk) and implemented corresponding strategies for outbreak control on 27 Feb 2020 [33]. This strategy was similar to Scenario 2 in our analysis (universal facemask wearing policy implemented in the epicenter/high-risk region). The experience in China during the COVID-19 outbreak shows that a universal facemask wearing policy should be introduced with caution. In addition,

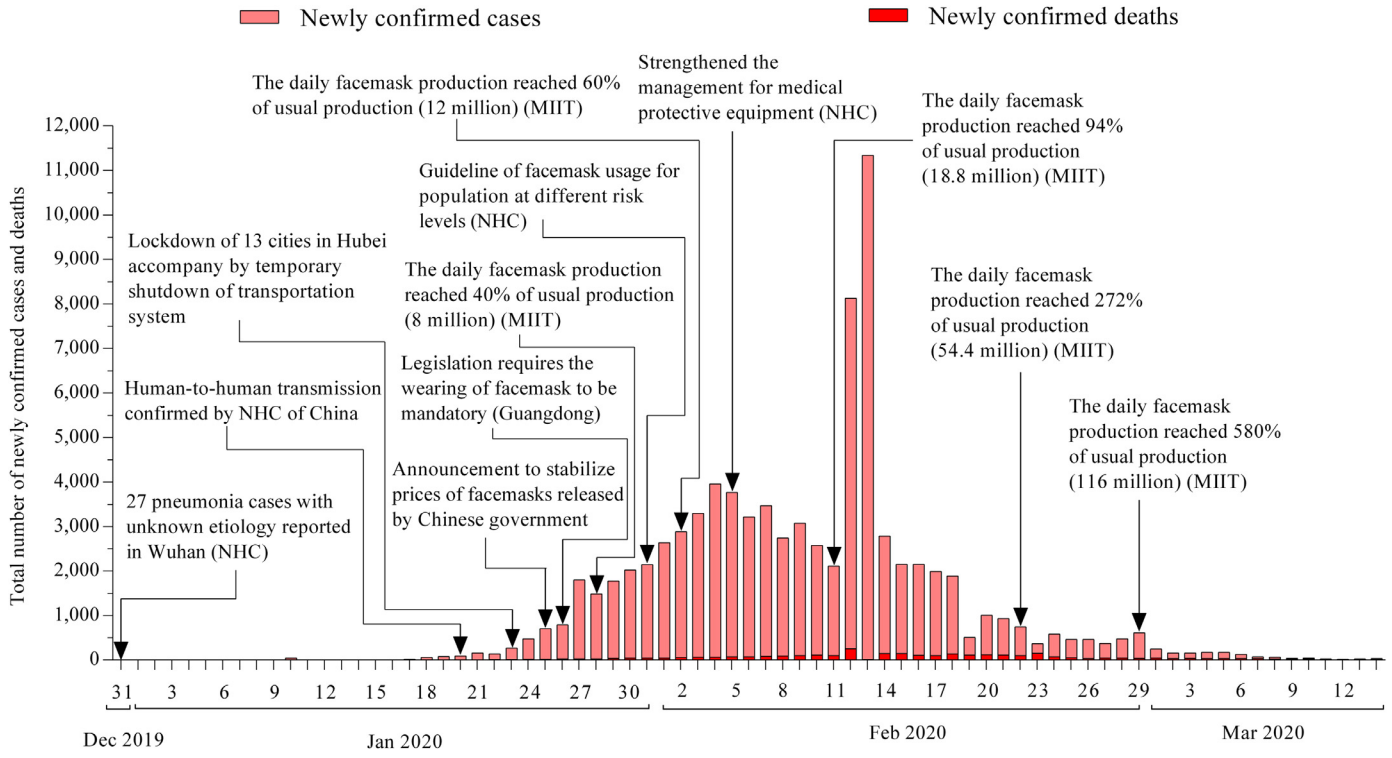

Fig. 1. Daily new confirmed cases and deaths during the novel coronavirus disease (COVID-19) outbreak in China. (Publicly available data from official websites of the National Health Commission (NHC), the Ministry of Industry and Information Technology (MIIT), the center for Disease Control and Prevention (CDC), and General Administration of Customs (GAC) of the People's Republic of China).

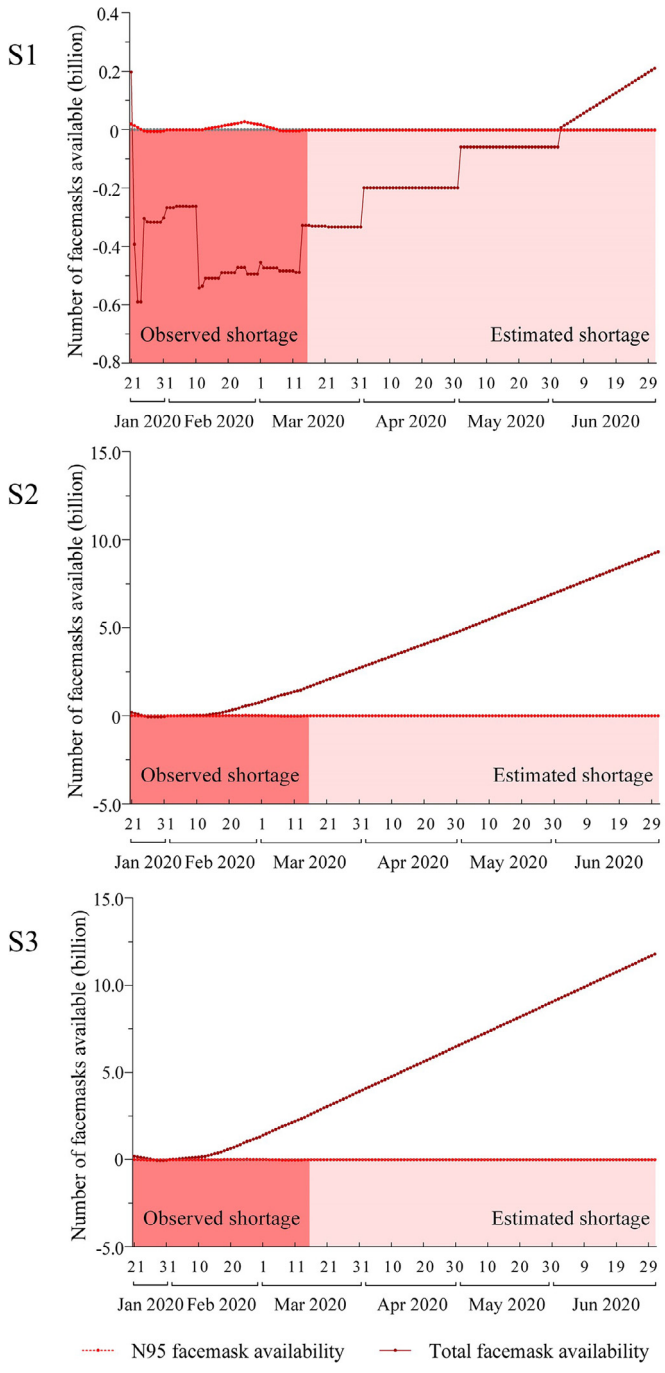

Fig. 2. Facemask availability during the novel coronavirus disease (COVID-19) outbreak in China (S1: assuming a universal facemask wearing policy implementation in all regions of mainland China; S2: assuming a universal facemask wearing policy implementation only in the epicenter (Hubei province, China); S3: Assuming no implementation of a universal facemask wearing policy).

both Hong Kong (with universal facemask wearing) and Singapore (without universal facemask wearing) experienced a slow increase in the number of new cases, indicating that a universal facemask wearing policy may not be necessary for outbreak control [34]. Given that the demand for facemasks can increase dramatically due to panic-buying, a universal facemask wearing policy in high-risk regions may be more appropriate to prevent massive asymptomatic infection. However, without effective public communication, a universal facemask wearing policy, even in specific regions, can result in panic throughout society and subsequently, increase the nationwide and worldwide demands for facemasks. These increased demands could cause a facemask shortage for healthcare workers and reduce the effectiveness of outbreak control in the affected regions, eventually leading to a pandemic.

To the best of our knowledge, this is the first study to investigate the facemask availability during the COVID-19 outbreak in China. We provided a detailed summary of the public health measures introduced by the Chinese government concerning facemasks and considered three facemask wearing policy scenarios. Nevertheless, there are some limitations in this study. First, our estimation relied on the assumptions of facemask productivity, import, storage, and need. Relevant information was limited at the time that the analyses were performed (during the epidemic). Second, we did not consider logistics cost that could restrict facemask supplies on the markets. Thus, our analysis is likely to underestimate the severity of the facemask shortage experienced by the healthcare workers and other user groups. Third, our prediction ended in late June considering the epidemic has been predicted to fade out by that time [17]. However, if imported infected cases cannot be controlled, the end of the epidemic will be delayed; thus, the daily incidence and facemask demand will also increase. Nevertheless, the anxiety in the population may result in constant demands for facemasks even when the epidemic is under controlled.

Implementing a universal facemask wearing policy in the whole of China could lead to severe facemask shortage. Although a universal facemask wearing policy in high-risk regions may be considered in order to prevent massive asymptomatic infection, nationwide or even worldwide facemask shortage is likely to occurred without effective public communication. Facemask shortage for healthcare workers would restrict the effectiveness of outbreak control in the affected regions and eventually lead to a pandemic. To fight novel infectious disease outbreaks, such as COVID-19, governments should monitor domestic facemask supplies and give priority to healthcare workers. Risk of asymptomatic transmission and facemask supply and demand should be carefully evaluated before introducing a universal facemask wearing policy in high-risk regions. Public health measures aimed at improving hand hygiene and effective public communication should be considered along with facemask wearing policy.

Declaration of Competing Interest

No conflicts of interest.

Data sharing statement

All data used in this study are publicly available. Data sources are described in the method section.

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Supplementary materials

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