



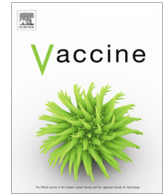
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## Would COVID-19 vaccination willingness increase if mobile technologies prohibit unvaccinated individuals from public spaces? A nationwide discrete choice experiment from China

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### ABSTRACT

**Background:** Achieving COVID-19 community protection (aka, herd immunity) in China may be challenging because many individuals remain unsure or are unwilling to be vaccinated. One potential means to increase COVID-19 vaccine uptake is to essentially mandate vaccination by using existing mobile technologies that can prohibit unvaccinated individuals from certain public spaces. The "Health Code" is a ubiquitous mobile phone app in China that regulates freedom of travel based on individuals' predicted risk of exposure to SARS-CoV-2. Green-colored codes indicate ability to travel unrestricted in low-risk regions; yellow-colored codes indicate prohibition from major public spaces and modes of public transportation. We examined the effects of a "Health Code"-based vaccine mandate on willingness to vaccinate for COVID-19 in China.

**Methods:** In August 2020, an online discrete choice experiment (DCE) was conducted among adults living in China. Participants completed up to six DCE choice sets, each containing two hypothetical COVID-19 vaccination scenario choices and a "do not vaccinate" choice. Half of the choice sets had a "Health Code" attribute that associated the "do not vaccinate" choice with a yellow Health Code implying restricted travel. Weighted, mixed effects multinomial logit regression was used to estimate preference utilities and predicted choice probabilities.

**Results:** Overall, 873 participants completed 4317 choice sets. Most participants attained at least college-level education (90.9%). 29.8% of participants were identified as vaccine hesitators (defined as being unsure or unwilling to receive a COVID-19 vaccination). With and without the "Health Code"-based vaccine mandate, there was an 8.6% (85% CI: 6.4% – 10.92%) and 17.3% (85% CI: 13.1% – 21.6%) respective predicted probability that vaccine hesitators would choose "do not vaccinate" over a common vaccination scenario currently in China (i.e., free, domestic vaccine, 80% effectiveness, 10% probability of fever side-effects, administered in a large hospital, two doses). Corresponding predicted probabilities for people who did not express vaccine hesitancy was 0.3% (93% CI: 0.0% – 14.3%) and 3.5% (93% CI: 2.3% – 4.8%). The "Health Code"-based mandate significantly increased willingness to vaccinate when vaccine efficacy was greater than 60%.

**Conclusion:** Among vaccine hesitators with higher educational attainment, willingness to vaccinate for COVID-19 appears to increase if mobile technology-based vaccine mandates prohibit unvaccinated individuals from public spaces and public transportation. However, such mandates may not increase willingness if perceived vaccine efficacy is low.

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## 1. Introduction

### 1.1. Background

As of 7 June 2021, there have been more than 3.7 million deaths from Coronavirus disease-2019 (COVID-19), causing unprecedented economic and social disruption [1]. Due in-part to limited healthcare resources and suboptimal recovery outcomes [2–3], COVID-19 vaccines are urgently needed to end the pandemic.

As of June 2021, there are 287 COVID-19 vaccine candidates under development, and five vaccines have been approved by the Chinese government [4–5]. Three vaccines require two doses and are developed by Sinopharm Beijing (79.34% efficacy for symptomatic COVID-19), Wuhan Co., Ltd. (72.51% efficacy), and Sinovac (50.65–91.25% efficacy, depending on trial location) [6–8]. A fourth vaccine is a single-dose adenovirus vector vaccine developed by CanSinoBio and which has shown 65.28% efficacy [9]. The fifth vaccine is a three-dose recombinant protein vaccine developed by the Institute of Microbiology of the Chinese Academy of Sciences and Anhui Zhifei Longcom Biopharmaceutical Co. Ltd., with 97% of vaccine recipients producing neutralizing antibodies [10].

Due to limited supply, COVID-19 vaccination campaigns in China initially targeted individuals engaged in medicine and healthcare, workers in public transportation, cold chain industry, and seafood markets, as well as priority groups traveling to high-risk countries or regions for work or study [11]. However, as COVID-19 vaccine stocks have increased in China, so too has access for the general population [12]. As of April 2021, virtually all adults residing in China are able to voluntarily receive free COVID-19 vaccination if they so wish [12].

However, despite the relatively rapid roll-out of free and voluntary COVID-19 vaccines, the vast majority of residents in China have not yet been vaccinated. As of June 6, 2021, only 29.24% of Chinese residents have been vaccinated for COVID-19 [13], coverage far lower than other countries such as Israel (92.46%) or the United Arab Emirates (60%) [14]. Moreover, China's suboptimal vaccination rate is of increasing concern because new COVID-19 variants are more infectious, thus raising the minimum vaccination coverage threshold needed to reach community protection (aka, herd immunity) [15]. According to one recent estimate, 85% of the population will need to be vaccinated to achieve immunity [15]. Unfortunately, one national survey indicated that only 67.1% of people in China are willing to vaccinate for COVID-19 [16]. Approximately 1 of 3 individuals in China exhibit vaccine hesitancy, defined by the WHO as “a delay in acceptance or refusal of acceptance of vaccines despite availability of vaccination services.” [17].

One potential means to augment COVID-19 vaccination rates is to implement vaccine mandates, defined as when “...vaccine refusal is legal, but when the state withholds from vaccine refusers social goods to which they would otherwise be entitled.” [18]. Vaccine mandates vary in form and severity, ranging from symbolic civil codes without any actual enforcement (aka mirage mandates) to harsh sanctions in the form of fines or imprisonment imposed on transgressors [19]. Studies from Europe and the United States indicate that mandatory vaccinations with penalties are associated with higher vaccination coverage [20].

In China, new mobile technologies developed in response to the COVID-19 pandemic have created new opportunities to rapidly implement broad vaccination mandates. The “Health Code” is a color-coded smartphone app used to classify individuals' risks of exposure to COVID-19 and serves as the basis for determining individuals' freedom of access to public spaces. A green color Health Code indicates a low risk of COVID-19 exposure, thus enabling the individual to move freely anywhere in low-risk geographic areas [21]. A yellow or red color code implies that the person has

been to medium or high-risk areas or has close contacts with confirmed COVID-19 patients and thus needs to be quarantined. Individuals with yellow or red color Health Codes are effectively barred from major modes of public transportation (e.g., train, planes, subway), residential compounds, and some public venues. Individuals without smartphones (e.g., some children or elderly people) can apply for a temporary Health Code at their local government office valid for a limited time period. Security personnel and doormen at public transportation stations, residential compounds, and public spaces are charged with checking individuals' Health Codes and enforcing exclusion of entry with force if necessary. If individuals with yellow or red Health Codes try to enter prohibited public areas, they might be suspected of not cooperating with pandemic prevention measures and may need to bear criminal responsibility if their actions significantly undermine public health [22]. The Health Code color is determined by smartphone Global Positioning System travel history (GPS), relationships with high-risk individuals, and personal information and self-reported physical conditions reported in the Health Code app [21]. Individuals who refuse to use the Health Code essentially forego their rights to access the aforementioned public spaces. Given its ubiquity in Chinese society today, the Health Code could be an efficient and rapidly scalable means of implementing a COVID-19 vaccine mandate.

In the current study, we sought to examine the extent to which individuals who do and do not express vaccine hesitancy in China are more willing to be vaccinated for COVID-19 if the Health Code is hypothetically used to exclude unvaccinated individuals from public spaces.

## 2. Methods

### 2.1. Study design

In August 2020, a discrete choice experiment (DCE) [23] was conducted to estimate effects of a “Health Code”-based vaccine mandate on willingness to vaccinate for COVID-19 in China. Participants were asked to complete six choice sets containing two kinds of hypothetical COVID-19 vaccination scenarios and a “do not vaccinate” option. The development of the DCE included three stages: 1) Attribute and level selection, 2) DCE and questionnaire design, 3) DCE implementation.

### 2.2. Identification of COVID-19 vaccine hesitators

The WHO defines vaccine hesitancy as “a delay in acceptance or refusal of acceptance of vaccines despite availability of vaccination services [24].” All participants were asked to endorse their level of agreement or disagreement with the following statement: “If a COVID-19 vaccine were available, I would get vaccinated.” Possible responses included “Strongly disagree”, “Disagree”, “Not Sure”, “Agree”, and “Strongly agree.” Vaccine hesitators were identified as people that selected “Not Sure”, “Disagree”, or “Strongly Disagree”. More specifically, those who endorsed “Not sure” were regarded as expressing a delay in vaccination acceptance, while those who endorsed “Disagree” or “Strongly Disagree” were regarded as expressing refusal of vaccine acceptance.

### 2.3. Attribute and levels selection

First, attributes and levels were selected by conducting fourteen one-on-one qualitative interviews (three males and eleven females, aged 20 to 74 years) that focused on personal perspectives and preferences regarding COVID-19 vaccines and vaccination. Throughout attribute development, experts from relevant fields (e.g., infectious diseases, vaccines, community health, etc.) pro-

**Table 1**  
Attributes and levels of the discrete choice experiment study.

Attribute and levels
Price(CNY)
0
100
500
1000
Origin of Vaccine
Imported
Domestic
Probability of fever side-effects (%)
10
30
Effectiveness (%)
40
60
80
90
Location of vaccination
Community health center
Big city hospital
Private clinic
Number of doses
1
2 <sup>a</sup>
3 <sup>b</sup>
Health Code color
Yellow <sup>c</sup>
Green <sup>d</sup>

Abbreviation: CNY, Chinese Yuan.

<sup>a</sup> Total of two doses, one at a time.

<sup>b</sup> Total of three doses, one at a time.

<sup>c</sup> The Health Code will be yellow if refusing vaccination.

<sup>d</sup> The Health Code will be green if choosing vaccination.

vided relevant feedback. Before finalizing attributes and levels, a pilot test of 20 participants recruited by convenience sampling was conducted. Finally, seven attributes with 20 associated levels were used to develop the DCE choice sets (Table 1). The Health Code was an alternative-specific attribute, whereby the two vaccination scenarios were associated with a green color Health Code, but the “do not vaccinate” option was associated with a yellow-colored Health Code. Labels and pictures were developed for each attribute level to make them intuitive and easily understandable.

#### 2.4. Experimental and questionnaire design

A d-efficient design matrix with 36 different choice sets within 12 blocks was produced with NGENE (ChoiceMetrics, 2014) to efficiently increase the precision of parameter estimates [23]. Each participant was randomly assigned to one of the twelve blocks. Every block consisted of six choice sets: three containing the Health Code attribute and three that did not. For each choice set, the participants were instructed to select one of two kinds of hypothetical COVID-19 vaccination scenarios or a “do not vaccinate” option. An example choice set is shown in Fig. 1. The design and number of blocks and choice sets were determined based on concerns of respondent cognitive burden, possible survey fatigue and requirements of statistical efficiency [25].

#### 2.5. DCE implementation

The DCE was conducted through online surveys in August 2020 using convenience sampling of individuals who met the eligibility criteria: over 18 years old, living in China and provided informed consent. Participant recruitment was conducted on various social media and internet platforms within China (e.g., Wechat and Weibo), whereby interested individuals could anonymously com-

plete the online survey. No material incentives were provided to study participants.

#### 2.6. Statistical analysis

DCE data were analyzed using multinomial mixed effects logit regression models. Effect coding was used for all attribute levels. Additionally, weights were constructed based on the national sex and age distribution of China, so that the analysis would be more generalizable to the general population [26]. The combination of the age and sex resulted in 16 cells (2 levels of sex \* 8 age groups = 16), illustrated in Table 2. To mitigate the influence of extremely large weights, weights among individuals over 50 years old were trimmed to be no greater than the median weight value + 6 times the inter-quartile range [27–28]. The analyses were conducted among the whole sample and among those who did and did not express vaccine hesitancy. All analyses used the MLOGIT package in R with 1000 Halton draws [29].

The probability of choosing the “do not vaccinate” alternative (choice “i”) rather than another hypothetical COVID-19 vaccination scenario (choice “j”) was estimated using Equation (1). Statistically significant effects of the Health Code on COVID-19 vaccination willingness were assessed by non-overlap of confidence intervals. To maintain a Type I error probability of 0.05 (i.e., alpha = 0.05), confidence intervals were set between 84% and 95%, depending on the ratio of standard deviations of the two groups being compared, as recommended by Knol et al [30]. 95% confidence intervals were not constructed by default because doing so would have led to an overly conservative alpha level of 0.0056 [30]. Confidence intervals for predicted choice probabilities were calculated using the Delta method [31]. In total, the “do not vaccinate” choice probabilities were calculated for sixteen plausible vaccination scenarios within China, based on the most recent vaccination information [6–10,32–34].

$$P_i = \frac{e^{\beta x_i}}{\sum e^{\beta x_j}} \quad (1)$$

#### 2.7. Ethical approval

Study protocols were approved by the Ethics Review Board of Xi'an Jiaotong-Liverpool University (protocol number: 19–03–85). Each participant provided informed consent prior to enrollment, and participation was anonymous.

### 3. Results

In 15 days, 970 individuals agreed to participate in the survey, 43 of whom did not meet the study eligibility criteria, and 54 of whom did not complete at least one choice set. Hence, 873 (90% of eligible respondents) completed 4317 choice sets. 29.78% of participants were identified as vaccine hesitators (defined as being unsure or unwilling to receive a COVID-19 vaccination).

#### 3.1. Participant characteristics and attitudes

Participant characteristics are presented in Table 2. Most participants were female (62.54%), between 18 and 24 years old (71.36%), and most attained at least college-level education (90.88%). Among participants, 38.83% felt they were at risk of becoming infected with COVID-19 and 46.62% were unsure about the safety of COVID-19 vaccines.

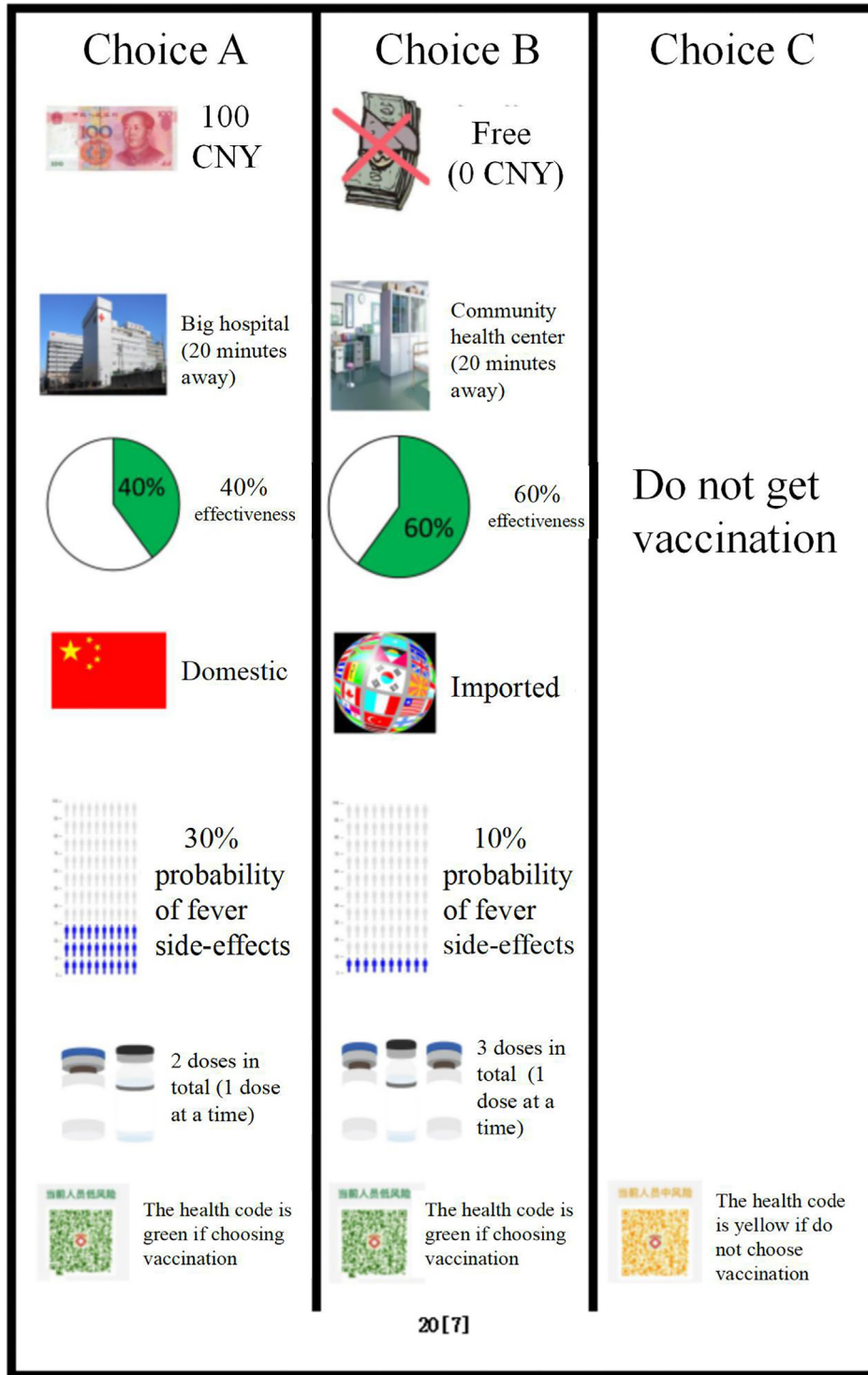


Fig. 1. Example of a choice set in the discrete choice experiment.

3.2. Multinomial mixed effects logit model

Table 3 shows parameter estimates for COVID-19 vaccination preferences, stratified by vaccine hesitation status. Participants preferred single dose vaccines, free vaccines, domestically produced vaccines, high effectiveness, and lower probability of fever side-effects. Among vaccine hesitators, choosing “do not vaccinate” was significantly less likely when “do not vaccinate was associated with a yellow color Health Code.

3.3. Estimated willingness to vaccinate

Figs. 2 and 3 present probabilities of choosing “Do not vaccinate” when compared to various vaccination scenarios among those who did and did not express vaccine hesitancy, respectively. Non-overlap of confidence intervals within the same hypothetical scenario indicates statistically significant difference (alpha = 0.05) in participants’ willingness to vaccinate for COVID-19 [30]. Scenarios 1 to 12 most closely reflect the current vaccination situation in



**Table 2**  
Characteristics of respondents (n = 873) (26) [51].

	Sample(n)	Sample(%)	Population, 1 k (N)	Population (%)	Weight
<b>Sex &amp; Age</b>					
Male					
18–24	226	25.89	48,706	5.31	0.21
25–29	32	3.67	47,710	5.20	1.42
30–34	8	0.92	46,843	5.11	5.58
35–39	19	2.18	41,517	4.53	2.08
40–44	14	1.60	42,557	4.64	2.89
45–49	17	1.95	52,108	5.68	2.92
50–54	3	0.34	48,939	5.34	5.79
55≥	8	0.92	134,047	14.62	5.79
Female					
18–24	397	45.48	42,647	4.65	0.10
25–29	42	4.81	45,268	4.94	1.03
30–34	20	2.29	46,358	5.06	2.21
35–39	24	2.75	40,370	4.40	1.60
40–44	26	2.98	41,017	4.47	1.50
45–49	26	2.98	50,276	5.48	1.84
50–54	7	0.80	47,911	5.23	5.79
55≥	4	0.46	140,457	15.32	5.79
<b>Educational attainment</b>					
High school and below	78	9.12	657,795	85.77	
College	676	79.06	105,050	13.70	
Masters and above	101	11.81	4,126	0.54	
<b>Ethnicity</b>					
Han	816	94.01	1,220,845	91.60	
Others	52	5.99	111,966	8.40	
<b>Region</b>					
North China	71	8.24	140,790	10.76%	
Northeast China	28	3.25	108,750	8.31%	
East China	464	53.83	390,550	29.85%	
Central south China	125	14.50	401,050	30.65%	
Southwest China	91	10.56	200,590	15.33%	
Northwest China	83	9.63	66,860,000	5.11%	
<b>Marital Status</b>					
Single	461	54.62			
Having boy/girl friend	207	24.53			
Married	165	19.55			
Divorced/widowed	10	1.18			
Others	1	0.12			
<b>Medical Insurance</b>					
Yes	751	92.72			
No	59	7.28			
<b>I am at risk of getting infected with COVID-19</b>					
Strongly agree	72	8.25			
Agree	267	30.58			
Not sure	246	28.18			
Not agree	131	15.01			
Strongly not agree	86	9.85			
<b>The COVID-19 vaccine will be safe</b>					
Strongly agree	50	5.73			
Agree	301	34.48			
Not sure	407	46.62			
Not agree	28	3.21			
Strongly not agree	4	0.46			
<b>Willing to get COVID-19 vaccination</b>					
Strongly agree	153	17.53			
Agree	369	42.27			
Not sure	237	27.15			
Disagree	19	2.18			
Strongly Disagree	4	0.46			

China. Generally, the probability of choosing “Do not vaccinate” was higher among those who showed COVID-19 vaccine hesitancy than those who did not express vaccine hesitancy. In addition, the Health Code attribute generally reduced the probability of selecting “Do not vaccinate”.

#### 3.4. Willingness to vaccinate by COVID-19 vaccine hesitancy

Among those hesitant to receive a COVID-19 vaccine, the Health Code appeared to significantly increase participants' willingness to vaccinate in some but not all vaccination scenarios. For example,

the Health Code appears to have reduced the probability of choosing “Do not vaccinate” from 17.34% (85% CI: 13.13% – 21.55%) to 8.61% (85% CI: 6.37% – 10.85%) when the vaccination scenario is a free, domestic vaccine with 80% effectiveness, 10% probability of fever side-effect, two doses, and administered in a big hospital (Fig. 2; Scenario 1). However, the Health Code does not appear to have had a significant effect on choosing “Do not vaccinate” when the hypothetical vaccine effectiveness is 60% or below and is administered in a community health clinic (Fig. 2; Scenario 5). The Health Code appeared to significantly increase COVID-19 vaccination willingness in scenarios 1, 2, 4, 7, and 10 (Fig. 2).

**Table 3**  
MXL model of COVID-19 vaccination preferences in China

	Vaccine Hesitators		Non-Vaccine Hesitators	
	With HCC	Without HCC	With HCC	Without HCC
	Coefficient			
Free	<b>0.231*</b>	<b>0.508***</b>	<b>0.629***</b>	<b>0.368***</b>
100CNY	<b>0.229**</b>	0.105	<b>-0.640***</b>	<b>0.160*</b>
500CNY	-0.139	<b>-0.290**</b>	0.113	<b>-0.355***</b>
1000CNY	-0.320	-0.323	-0.103	-0.174
Imported	<b>-0.185***</b>	-0.067	<b>-0.851***</b>	<b>-0.452***</b>
Domestic	0.185	0.067	0.851	0.452
10% probability of fever side effects	<b>0.176***</b>	<b>0.238***</b>	<b>0.562***</b>	<b>0.186***</b>
30% probability of fever side effects	-0.176	-0.238	-0.562	-0.186
40 %effectiveness	<b>-0.991***</b>	<b>-1.161***</b>	<b>-1.822***</b>	<b>-1.429***</b>
60 %effectiveness	<b>-0.423***</b>	<b>-0.222*</b>	<b>-0.764***</b>	<b>-0.369***</b>
80 %effectiveness	<b>0.874***</b>	<b>0.836***</b>	<b>1.724***</b>	<b>0.809***</b>
90 %effectiveness	0.539	0.546	0.862	0.989
Community Health Center	<b>-0.273***</b>	-0.069	0.154	-0.070
Big Hospital	0.155	<b>-0.283**</b>	<b>-0.776***</b>	<b>0.181*</b>
Private Clinic	0.118	0.215	0.622	-0.111
1 dose	<b>0.354***</b>	<b>0.237**</b>	<b>0.590***</b>	<b>0.270***</b>
2 dose	-0.004	<b>0.166*</b>	<b>0.243**</b>	-0.017
3 dose	-0.350	-0.403	-0.833	-0.252
Opt out	<b>-0.746***</b>	-0.030	<b>-2.648***</b>	<b>-1.325***</b>

\*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001.

HCC: Health Code Color;

The bold data indicate the standard deviation estimates of coefficients are statistically significant.

Among those not hesitant to receive a COVID-19 vaccine, the Health Code also appeared to significantly increase participants' willingness to vaccinate in some but not all vaccination scenarios. For example, the Health Code appears to have reduced the probability of choosing "Do not vaccinate" from 13.77% (86% CI: 10.80% – 16.75%) to 0.82% (87% CI: 0.00% – 2.03%) when the vaccination scenario is a free, domestic vaccine with 60% effectiveness, 10% probability of fever side-effect, one or two doses, and administered in a private clinic (Fig. 3; Scenario 6). The Health Code appeared to significantly increase COVID-19 vaccination willingness in scenarios 6, 9, 11, 14, 15, and 16 (Fig. 3).

#### 4. Discussion

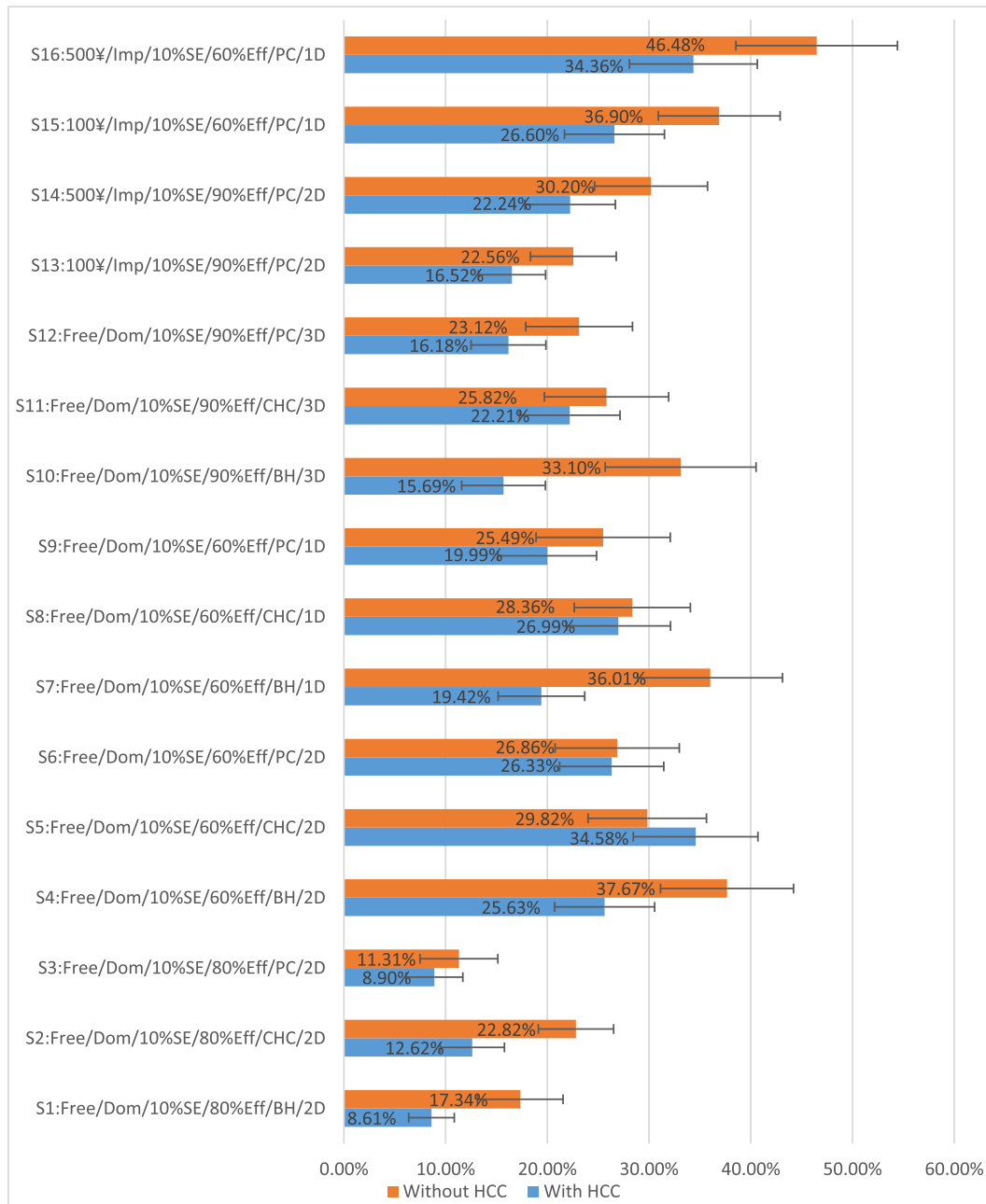
Increasing COVID-19 vaccination coverage is a major goal of countries throughout the world to combat the spread of SARS-CoV-2. However, refusing or delaying COVID-19 vaccination is common worldwide and in China. To the best of our knowledge, this study is the first to quantitatively demonstrate that those hesitant to receive a COVID-19 vaccine in China are more willing to be vaccinated for COVID-19 if mobile technologies are used to exclude unvaccinated individuals from public spaces. These findings are instructive for policy makers seeking to augment COVID-19 vaccination rates in China, especially given low rates of influenza vaccination among adults during the H1N1 pandemic in 2009 [35].

Access, affordability, awareness, and acceptance have been identified as the key drivers of suboptimal vaccination rates [35]. Given the wide publicity and increasing availability of free COVID-19 vaccines in China as of June 2021, public acceptance likely poses the most formidable challenge to achieving optimal vaccination rates in China. Similar to previous surveys [16], we found that approximately only 67% of participants explicitly expressed willingness to be vaccinated for COVID-19. Hence, it appears unlikely that community protection against COVID-19 can be achieved by exclusively relying on those who have already agreed to vaccinate. Mandates and activation "nudges" [36] are likely needed to encourage vaccine uptake among those ambivalent or disinclined to vaccinate.

Gradually escalating vaccination incentives and sanctions over time may be a promising strategy to increase vaccination rates while minimizing potential risk to public trust. For example, numerous provinces in China have already begun to incentivize vaccination by issuing special gold-colored Health Codes and digital badges for individuals who voluntarily completed their COVID-19 vaccination regimens [37]. Establishing such pro-vaccination social norms and status symbols may help persuade some vaccine hesitant individuals to vaccinate, but realistically may not be sufficiently salient to motivate vaccine hesitant individuals who hold serious concerns about COVID-19 vaccine efficacy and side-effects [38].

If necessary, using the Health Code to exclude unvaccinated individuals from public spaces may be a rapidly scalable and salient means of increasing COVID-19 vaccine willingness in China. First, the Health Code app is already firmly embedded within the daily lives of most residents of China [38]. Not only is the Health Code app infrastructure already well established, but its regulation of access to public space has already been normalized throughout society [39]. In fact, as the COVID-19 vaccination campaigns accelerate nationwide, the "Health Code" is already being linked to individuals' vaccination records. As of June 19, 2021, unvaccinated individuals were still able to obtain a Green "Health Code" [40]. Second, results from the current study strongly suggest that both those who did and did not express vaccine hesitancy were more willing to vaccinate for COVID-19 if their Health Code color is tied to their vaccination status. It is worth noting that, the salience of the Health Code appeared to be greater for vaccinations occurring in big hospitals compared to private clinics and community health centers. In addition, even when a yellow color Health Code was associated with refusal to vaccinate, probabilities of vaccine refusal remained relatively high when vaccine efficacy was  $\leq 60\%$  or lower (additional results available upon request), and when the vaccine was a fee-based foreign brand. Further studies are needed to elucidate the mechanisms of these findings.

As a last resort, criminalization and coercion are theoretically possible if all other strategies have failed to adequately raise COVID-19 vaccination rates. According to the 2019 Vaccination Law of China, Chinese citizens residing in China are obliged to be



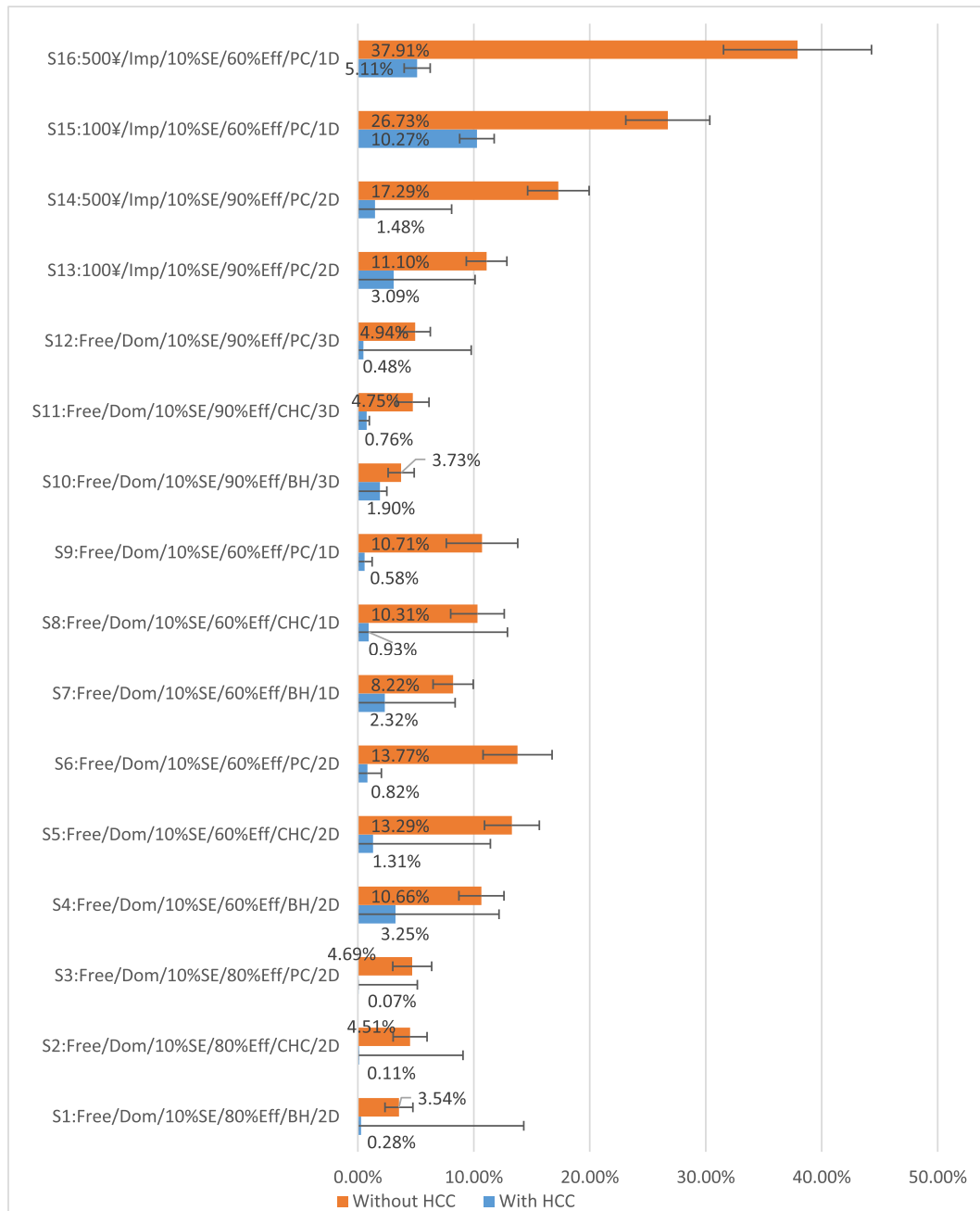
**Fig. 2. Predicted probability of Selecting 'Do Not Get Vaccination' With Different Scenarios Among Vaccine Hesitators.** S = Scenario; HCC: Health Code Color; 100¥=100CNY; 500¥=500CNY; Dom = Domestic; Imp = Imported; 10 %SE = 10% Probably of fever side-effects; 60 %Eff = 60% Effectiveness; 80 %Eff = 80% Effectiveness; 90 % Eff = 90% Effectiveness; BH = Big Hospital; CHC = Community Health Center; PC = Private Clinic; 1D = One Dose; 2D = Two Doses; 3D = Three Doses.

vaccinated with vaccines listed in the national program schedule [41]. Hence, citizens could theoretically be legally obliged to vaccinate for COVID-19 if it were added to the vaccination schedule. However, despite having legal means to pressure COVID-19 vaccination, the government appears reluctant to adopt such severe sanctions at this time [42]. Broad coercive vaccine mandates have high potential to profoundly undermine public trust and should only be considered in the direst public health emergencies. Due partly to the relatively low number of COVID-19 cases in China after the initial outbreak in early 2020 [43], the general public may feel that such coercive measures at this time are unnecessary. Moreover, public confidence in vaccines has already been shaken by several high-profile cases of substandard vaccine production practices in recent years [44–45], and cannot be taken for granted.

It is also important to remember that a minority of the population will refuse to vaccinate for COVID-19 no matter what incentives or sanctions are imposed. Some adamant vaccine refusals will be based on medical conditions such as allergies or immunocompromised states, and must be granted medical exemptions [46]. In order to discourage prevarication about one's true medical condition, vaccine medical exemptions should be conditioned on the judgement of professional health care providers, rather than solely self-report. Qualitative research on Health Code usage in China suggests that some individuals will deliberately misreport essential data in order to avoid travel restrictions [39].

Invariably, some individuals will refuse vaccination, even without medical contraindications. For example, religious beliefs and conscientious objection are common non-medical reasons for vac-





**Fig. 3. Predicted probability of Selecting 'Do Not Get Vaccination' With Different Scenarios Among Non-Vaccine Hesitators** S = Scenario; HCC: Health Code Color; 100¥=100CNY; 500¥=500CNY; Dom = Domestic; Imp = Imported; 10 %SE = 10% Probably of fever side-effects; 60 %Eff = 60% Effectiveness; 80 %Eff = 80% Effectiveness; 90 % Eff = 90% Effectiveness; BH = Big Hospital; CHC = Community Health Center; PC = Private Clinic; 1D = One Dose; 2D = Two Doses; 3D = Three Doses.

cine refusals in the North America [47], despite evidence that non-medical exemption (NME) policies appear significantly associated with higher disease incidence [48]. Historically, NMEs have not been institutionalized in China, and policy makers must carefully consider if NMEs should be issued for COVID-19 vaccines. Formalizing NMEs for COVID-19 vaccination could lead to calls for NMEs to be issued for additional vaccines. If COVID-19 vaccination NMEs are indeed issued, then it will be critical that those seeking NMEs comply with educational and administrative requirements. For example, NMEs in Germany are only issued to parents after they have completed an educational workshop so that they fully understand the medical implications of refusing vaccination [47]. Imposing such requirements will also help encourage vaccination uptake among those able to vaccinate but are simply unwilling to com-

plete the administrative procedures [47]. In any case, in the longer term, future research and policies should focus on addressing the structural drivers of vaccine hesitancy in China. Widely publicized cases of substandard vaccine production and administration in recent years have undermined public trust in vaccines, and must be restored through greater regulatory measures, transparency, and public engagement [44].

### 5.1. Limitations

Our study has several limitations. First, compared to China's general population, our study sample was relatively young and had high levels of educational attainment. We weighted the sample by age and sex to make the sample more reflective of China's

general population, but results may have limited generalizability to individuals with lower educational attainment. Second, the study did not exclude people who were already vaccinated for COVID-19, had recovered from COVID, or had medical issues precluding vaccination. Nevertheless, at the time of the survey, the vast majority of the population did not belong to any of the aforementioned groups [49]. Third, the study only elucidated participants' stated choices, which is distinct from actual behavior. However, evidence suggests that real-world human behavior is closely associated with DCE results [50]. Fourth, our DCE study was conducted in August 2020, when the COVID-19 vaccine was not available in China. As COVID-19 vaccination campaigns have expanded and more individuals become vaccinated, COVID-19 vaccination preferences may have changed since the study data were collected. Lastly, we did not assess how trust and attitudes towards the government may be impacted if the Health Code is used to restrict unvaccinated individuals from public spaces, even if vaccination willingness is increased.

## 5. Conclusion

Findings from this nationwide DCE study indicate that among individuals with higher educational attainment, willingness to vaccinate for COVID-19 in China will increase if the Health Code is used to restrict unvaccinated individuals from public spaces, assuming that vaccine efficacy is greater than 60%. If necessary, policy makers in China can consider using the Health Code to mandate COVID-19 vaccination uptake, but exemption procedures and impacts on public trust must be carefully deliberated and balanced.

### Compliance with ethical standards

Study protocols were approved by the Ethics Review Board of Xi'an Jiaotong-Liverpool University. Each participant provided informed consent prior to enrollment, and participation was anonymous.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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