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A cross-national study of multilevel determinants on public fully vaccination against COVID-19

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ABSTRACT

The pandemic caused by SARS-CoV-2 (COVID-19) has impacted the world for close to three years and led to substantial costs to public well-being. To mitigate the pandemic's damage, the most effective approach lies in the vaccine. This study aims to investigate multilevel predictors of the public decision to become fully vaccinated against COVID-19. Data from a cross-national survey on representative samples are merged with country-level indicators. Multilevel logistic regression models are estimated on populations from 15 countries. Findings show that people who agree the government handles the pandemic well, believe the health officials would provide an effective vaccine, perceive the virus's danger, and are older are more likely to get fully vaccinated than their counterparts. Meanwhile, the national case rate and vaccination rate also affect one's decision to become fully vaccinated. Furthermore, there are significant cross-level interactions as people are more inclined to become fully vaccinated if they agree with the government's performance, perceive the virus's danger, and also reside in countries with higher case and vaccination rates. This study shows cross-national evidence regarding multilevel determinants of public vaccine uptake. Knowing the profiles among populations who have become fully vaccinated or not helps public health experts leverage factors and maximize vaccination.

1. Introduction

The pandemic caused by SARS-CoV-2 (COVID-19) has impacted the world for close to three years. The most recent data from Johns Hopkins University's Dashboard show that approximately 658 million people have been infected and over 6.7 million people have lost their lives by December 2022, which is likely an underestimation of the actual infections and deaths (Krymova et al., 2022). The Delta variant has caused an exponential increase in cases, as have the Omicron variant and its contagious subvariants (e.g., BA.4 and BA.5) continue to speed up transmission. To mitigate the pandemic's damage to public well-being and reduce socioeconomic costs, countries worldwide have adopted numerous response measures, and the most effective approach to mitigation is vaccination (Goel et al., 2021; Vu et al., 2021; Wang et al., 2022).

Despite proven efficacy of several vaccines, vaccine hesitancy and resistance remain (Awijen et al., 2022; Larson and Broniatowski, 2021; Machingaidze and Wiysonge, 2021; Troiano and Nardi, 2021). Vaccination rates are low, with only 66% of the global population being fully vaccinated, according to the latest information released by the Our World in Data project (Mathieu et al., 2021). The persistent pool of

unvaccinated people posed a significant risk for the emergence of new variants of concern. Against this backdrop, it is important to understand the public opinion on the COVID-19 vaccine. Most studies on this topic emphasize a single country such as the United States (Szilagyi et al., 2021), the United Kingdom (Becchetti et al., 2021), Germany (Seddig et al., 2022), Italy (Capasso et al., 2021), Netherlands (Mouter et al., 2022), Sweden (Campos-Mercade et al., 2021), Turkey (Dal and Tokdemir, 2022), Japan (Sasaki et al., 2022), and Singapore (Tan et al., 2022). However, few studies analyze data across countries (Barceló et al., 2022; Breslin et al., 2021; Hess et al., 2022; Lazarus et al., 2021; Murphy et al., 2021; Neumann-Böhme et al., 2020). More importantly, these cross-national studies typically use surveys before the vaccine is available and thus focus on people's willingness to take the vaccine, not gauging whether people had taken the vaccine. Also, the country-level predictors received less attention in the existing literature compared to individual-level predictors. In response to the evolving pandemic, more research is needed to explore the behavior of getting fully vaccinated across countries and the multilevel determinants that promote vaccine uptake.

This study aims to complement the literature by investigating data from 15 countries worldwide using a survey conducted in September

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2021. Compared to studies that only focused on a single country, the data is more inclusive and the findings might be more meaningful because the pandemic is a global crisis. In addition, instead of evaluating vaccine acceptance or vaccination intention, the COVID-19 vaccine uptake is used as the primary measure, which might be more accurate to gauge one’s attitude towards the vaccine. Furthermore, this study includes predictors beyond individual-level variables. Multilevel logistic regression is estimated to analyze personal characteristics (view of the government and risk perception) and national contexts (case rate and vaccination rate) that, independently or interactively, shape individual decisions to become fully vaccinated against COVID-19. The findings help distinguish between the fully vaccinated population and others who are hesitant to take the vaccine and provide public health officials with insights to target promotion of the vaccine to hesitant populations.

2. Data and variables

This study includes data from several sources. All individual-level data is from the COVID-19 behavior tracker project run by the Institute of Global Health Innovation at Imperial College London. The market research company YouGov administered the survey. By surveying people worldwide over a week-long period since March 2020, the project aims to gather global information on public responses to the pandemic and help health experts mitigate its impact (Jones, 2020). This study uses the survey administered on the week of September 20th, 2021. More than 25,000 respondents 18 years and older from 15 countries across Europe, North America, Asia, and Australia completed the survey online, where vaccine rollouts were sufficient during the survey period. The list of countries is presented in Table 1. One common characteristic of these countries is that they all fall into the high-income category and are equipped with sufficient resources such as vaccine doses to respond to the pandemic, which might make it reasonable to combine these countries for this study of public vaccine uptake. Nevertheless, these countries have great heterogeneity regarding geographic location, cultural orientation, and values systems that could impact the analyses. This limitation is discussed at the end of the manuscript.

This survey wave is the last one carried out on all these countries, and four countries (Singapore, South Korea, Sweden, and United States) were dropped in the subsequent waves. The participants are from nationally representative samples of the general public of each country. Questions cover their attitudes regarding the pandemic, behavioral responses, and measures of their sociodemographic backgrounds. A weighting variable is available to improve the representativeness of the data, and as described in the method section, the regression estimation is weighted using the weighting score. The data can be downloaded from a GitHub website (github.com/YouGov-Data/covid-19-tracker) and available to view at a dashboard (www.coviddatabook.com). The variables are introduced below, with the descriptive statistics reported in Table 2.

The dependent variable is one’s vaccination status. One question asks participants whether they have gotten the first or second doses of a COVID-19 vaccine. Responses include “yes, two doses” (76%), “yes, one dose” (10%), and “no, neither” (14%). The last two categories are combined, and the variable is recoded binary suggesting that people are fully vaccinated (1) or not (0). Respondents from each country have different perceptions of vaccine uptake, as presented in Fig. 1. Over 80% of respondents from countries such as Canada, Denmark, Singapore, and

Table 1
List of countries (n = 15).

Australia	Israel	South Korea
Canada	Italy	Spain
Denmark	Japan	Sweden
France	Netherlands	United Kingdom
Germany	Singapore	United States

Table 2
Descriptive statistics.

Variable	Mean	S.D.	Min	Max
<i>Dependent Variable</i>				
Fully vaccinated	0.761	0.426	0	1
<i>Individual-Level Independent Variables</i>				
View of the government handling the pandemic	2.445	0.945	1	4
View of the government providing effective vaccine	3.512	1.272	1	5
COVID-19 is very dangerous for me	4.298	1.925	1	7
My life has been greatly affected by COVID-19	4.472	1.914	1	7
Age	48	17	18	98
Gender (Male = 1)	0.484	0.500	0	1
<i>Country-Level Independent Variables</i>				
Case rate (confirmed cases/population)	0.073	0.049	0.004	0.147
Vaccination rate (fully vaccinated/population)	0.639	0.103	0.414	0.775

The values represented unweighted scores or percentages.

the United Kingdom said they are fully vaccinated, while a low percentage of respondents from other countries such as Australia (52%), Japan (59%), South Korea (42%), and the United States (61%) said they are fully vaccinated.

There are six individual-level independent variables. Two of these independent variables measure participants’ views of the government. First, participants were asked about how the government is handling COVID-19. Responses and coding include very badly (1), somewhat badly (2), somewhat well (3), and very well (4). Second, participants were asked about their opinion on whether government health authorities can provide an effective COVID-19 vaccine. Responses range from strongly disagree (1) to strongly agree (5). In addition, two variables measure one’s risk perception by asking participants how they respond to a statement saying COVID-19 is very dangerous and another statement saying life has been greatly affected by COVID-19. Responses were recorded on a seven-point Likert scale (1 = disagree and 7 = agree). The sociodemographic variables include age (measured in years) and gender (male = 1). The number of variables is constrained in this study because some variables (e.g., income and education) are not included in the survey while others are only available in some of these countries. These limitations are discussed at the end of this article.

Two country-level variables are merged with individual-level data drawn from the survey. Each country’s cumulative cases for the days when the survey was conducted are assembled and the average is divided by population to calculate the case rate. This information is obtained from a dataset assembled by Johns Hopkins University and published on a GitHub website (Dong et al., 2020). Its sources include the World Health Organization, European Centre for Disease Prevention and Control, the United States Centers for Disease Control and Prevention, etc. The vaccination rate is computed by taking the proportion of fully vaccinated people out of the total population at the time of survey administration. This indicator is extracted from the Our World in Data project managed by the University of Oxford that collects information from the World Health Organization and the Ministry of Health for individual countries (Mathieu et al., 2021). These two variables have been transformed into the logarithmic form to correct skewness when included in regression analyses.

3. Methods and results

Multilevel logistic regression with random intercepts is employed to assess the influence of individual-level and country-level predictors on one’s decision to get fully vaccinated. Multilevel modeling is used because the data is hierarchical with two levels, and the individual units of analysis at a lower level are nested within the country units at a higher level. The logistic model is adopted because the dependent variable is coded binary. In the analyses, explanatory variables are fixed and not

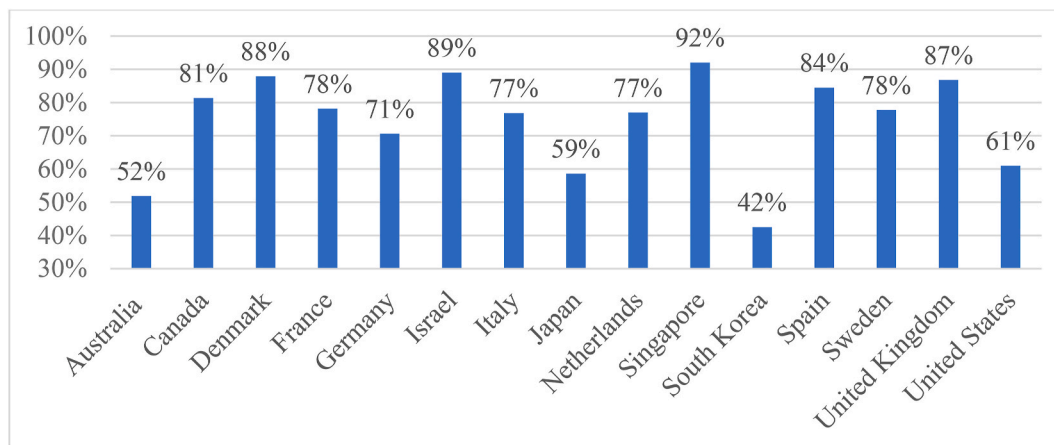


Fig. 1. Percent of Respondents said being Fully Vaccinated.

allowed to vary across states. However, a random intercept controls the different means in one’s decision to become fully vaccinated across countries and helps reveal whether the cross-country variation in the intercepts depends on the country-level variables (Robson and Pevalin, 2016; Snijders and Bosker, 2012).

The analyses are performed in different models, step-by-step as shown in Table 3. Model 3.1 includes six individual-level independent variables. The two country-level variables (case and vaccination rates) are added in Models 3.2 and 3.3, respectively. Next, this study tests the effect of cross-level interactions on one’s vaccination status and the results are presented in Table 4. The data have been weighted for regression to ensure that the sample characteristics of age, gender, and geographical distribution matched known parameters of the population. The findings are reported as odds ratios. The models are estimated on a total of 23,394 respondents out of 25,014 survey participants from these 15 countries. The difference is due to missing values in the variable of the public view of the government handling the pandemic (6% missing). A multiple imputation approach addresses the concern and more details are provided at the end of this section.

An intercept-only model is estimated with no predictors in the preliminary analysis to test whether multilevel modeling is needed. The intraclass correlation value is 0.144, suggesting approximately 14% of the variance in the dependent variable occurs between countries and multilevel specification is reasonable for analysis (Hox, 2002).

Model 3.1 shows that one’s view of the government and risk perception is significantly associated with vaccination status. The odds of people becoming fully vaccinated increase by 35.1% for a one-unit increase in their agreement that the government is handling the pandemic well. The odds increase by 66.6% for a one-unit increase in consensus the government would provide an effective vaccine. Also, people are more likely to become fully vaccinated if they perceive the

danger of COVID-19 (odds ratio = 1.100). In addition, the odds of being fully vaccinated increase by 3.5% for each year increase in age. The statistical significance of these variables remains in subsequent models after adding country-level variables. The perceived impact of the pandemic and gender have insignificant influences. The effects of these individual-level predictors on public vaccination status with 95% confidence intervals are presented in Fig. 2. The effects of these predictors for each country are also estimated separately using logistic regression and the results are presented as a combined figure in Appendix 1.

Next, the country-level predictors are added for examination. Results in Model 3.2 suggest that people from countries with a higher case rate are more likely to become fully vaccinated. The odds increase by 64.7% for each point increase in case rate. Meanwhile, Model 3.3 shows that people from countries with a high full vaccination rate are considerably more likely to become fully vaccinated (odds ratio = 83.514). To further examine the effect of these two variables, the associations are visualized by computing the adjusted means of the odds of becoming fully vaccinated given different values of case rate and vaccination rate after controlling for other variables in the models. As presented in Fig. 3, the estimated odds of becoming fully vaccinated increase concomitantly with either case rate or vaccination rate growth.

Furthermore, this study examines the interactions between three significant individual-level predictors and the country-level variables, and the results are reported in Table 4. The positive effects of three individual-level predictors (the view of the government handling the pandemic, the view of the government providing an effective vaccine, and the perceived danger of COVID-19) are greater among people from countries with higher case rates (Models 4.1–4.3). Also, the effects of individual views on the government are stronger for people from countries with higher vaccination rates (Models 4.4–4.5). The interaction effects between age and country-level factors have been tested and

Table 3
Multilevel logistic regression results in odds ratio.

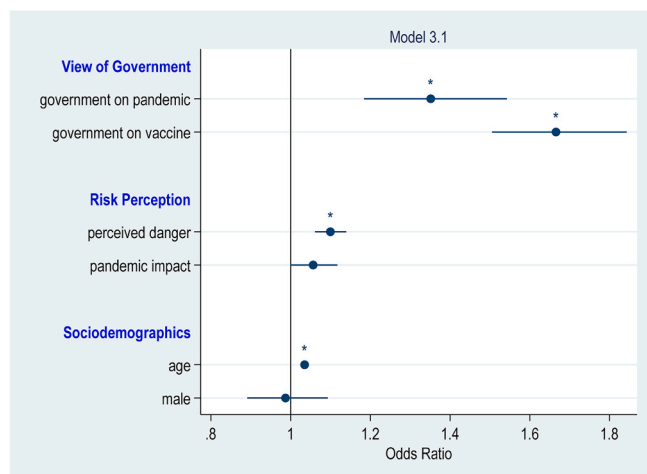
	Model 3.1	Model 3.2	Model 3.3
<i>Individual-Level Independent Variables</i>			
Government on pandemic	1.351*** (0.091)	1.352*** (0.091)	1.351*** (0.091)
Government on vaccine	1.666*** (0.086)	1.666*** (0.086)	1.666*** (0.086)
COVID-19 is very dangerous	1.100*** (0.020)	1.100*** (0.020)	1.100*** (0.020)
My life has been affected by COVID-19	1.056 (0.030)	1.056 (0.030)	1.057 (0.030)
Age	1.035*** (0.004)	1.035*** (0.004)	1.035*** (0.004)
Male	0.987 (0.051)	0.987 (0.051)	0.987 (0.051)
<i>Country-Level Independent Variables</i>			
Case Rate (ln)	-	1.647** (0.259)	-
Vaccination Rate (ln)	-	-	83.514*** (58.327)
<i>Model Statistics</i>			
Constant	0.035	0.162	0.273

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

Table 4
Multilevel logistic regression results with cross-level interactions in odds ratio.

	Model 4.1	Model 4.2	Model 4.3	Model 4.4	Model 4.5	Model 4.6
<i>Individual-Level Independent Variables</i>						
Government on pandemic	2.126*** (0.293)	1.351*** (0.092)	1.347*** (0.093)	2.180*** (0.316)	1.351*** (0.092)	1.348*** (0.092)
Government on vaccine	1.658*** (0.090)	2.315*** (0.280)	1.664*** (0.086)	1.658*** (0.089)	2.290*** (0.288)	1.665*** (0.086)
COVID-19 is very dangerous	1.097*** (0.021)	1.098*** (0.021)	1.249*** (0.037)	1.097*** (0.021)	1.099*** (0.020)	1.182*** (0.057)
My life has been affected by COVID-19	1.054 (0.030)	1.055 (0.030)	1.056 (0.030)	1.055 (0.030)	1.057* (0.030)	1.057 (0.030)
Age	1.035*** (0.004)	1.035*** (0.004)	1.035*** (0.004)	1.035*** (0.004)	1.035*** (0.004)	1.035*** (0.004)
Male	0.988 (0.053)	0.990 (0.053)	0.990 (0.052)	0.990 (0.053)	0.992 (0.054)	0.989 (0.052)
<i>Country-Level Independent Variables</i>						
Case Rate (ln)	1.203 (0.174)	1.169 (0.167)	1.381 (0.231)	-	-	-
Vaccination Rate (ln)	-	-	-	8.748** (5.856)	9.381** (6.746)	43.418*** (39.107)
<i>Cross-Level Interactions</i>						
Government on pandemic × Case Rate	1.147*** (0.036)	-	-	-	-	-
Government on vaccine × Case Rate	-	1.110*** (0.030)	-	-	-	-
COVID-19 is very dangerous × Case Rate	-	-	1.041*** (0.008)	-	-	-
Government on pandemic × Case Rate	-	-	-	2.566*** (0.546)	-	-
Government on vaccine × Case Rate	-	-	-	-	1.936** (0.371)	-
COVID-19 is very dangerous × Case Rate	-	-	-	-	-	1.159 (0.103)
<i>Model Statistics</i>						
Constant	0.061	0.057	0.096	0.092	0.097	0.202

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



*Refers to statistically significant coefficients

Fig. 2. Effects of Individual-level Predictors on Public Decision of becoming Fully Vaccinated.

*Refers to statistically significant coefficients.

the findings are statistically insignificant. The associations between these interactions and one’s vaccination status are also visualized in two figures. Fig. 4 presents how the effects of three individual predictors vary depending on the case rate at the country level. Fig. 5 shows how the effects of two individual predictors differ depending on the vaccination rate at the country level. Accordingly, these individual factors’ effects on the estimated odds of people becoming fully vaccinated are more substantial if they are from countries with higher case/vaccination rates (the slopes are steeper and maintain a positive trend) than moderate and low rates (the slopes are relatively flat or have a negative trend).

Multiple diagnostics were run to check the model. The AIC and BIC scores to evaluate models in terms of parsimony/complexity and statistical fit decrease as country-level measures are included, suggesting better-fitting models. The tests for multicollinearity find no problem. The R-square values indicate that the country-level variables account for around 65% of the variance in personal decisions to become fully vaccinated and individual-level variables explain 17% of the variance in the dependent variable. To address the missing value issue, 20 datasets with complete data are generated using the multiple imputation

approach (Royston, 2004). Regression analyses of these data after imputing missing values produce analogous results as reported in this section.

4. Discussion and conclusion

The COVID-19 pandemic imposes enormous morbidity and mortality burdens, disrupting societies and economies globally (Josephson et al., 2021). New variants plus relaxed precautions against viral transmission might fuel another outbreak worldwide with spikes in coronavirus infections. At the same time, different types of vaccines have been made available to an increasing proportion of people. While science informs the public that the vaccine can reshape the pandemic’s course, many people still hesitate or resist the vaccine (Machingaidze and Wiysonge, 2021; Troiano and Nardi, 2021). Thus, it is critical to understand how to persuade a sufficient proportion of the global population to fully vaccinate against COVID-19 (Wang et al., 2021). This study examines data from 15 countries and the findings shed light on multilevel determinants that nudge one’s vaccine uptake.

At the individual level, participants who have a positive view of the government, higher risk perception, and who are older are more likely to become fully vaccinated than their counterparts. At the country level, one’s vaccination status is positively associated with the case rate. Previous studies in the United States found that people from states with higher case rates are more likely to keep social distance and wear a face mask in response to COVID-19 (Hao and Shao, 2021; Hao et al., 2021). The underlying argument is that people sense a more severe threat in these states and are thus more motivated to take preventive measures. Following this logic, people from countries exposed to more confirmed cases become fully vaccinated to reduce the chance of infection. Meanwhile, a high vaccination rate can motivate individuals to become fully vaccinated. This finding might be because the vaccination rate at the collective level could create a social norm and powerful peer pressure to encourage individual vaccine uptake. There is a distinct social identity between people who have taken the vaccine and those who resist the vaccine (Motta et al., 2021). The people who tend to be vaccinated derive social benefits from their various social groups’ positive views on vaccination, leading to vaccine uptake to conform to group expectations. A previous study of Americans supports the argument by showing that residents are more likely to take the vaccine if they are from states with higher vaccination rates (Hao and Shao, 2022). Furthermore, the magnitude of the effects for these individual-level factors depends on various scenarios at the country level. Significant

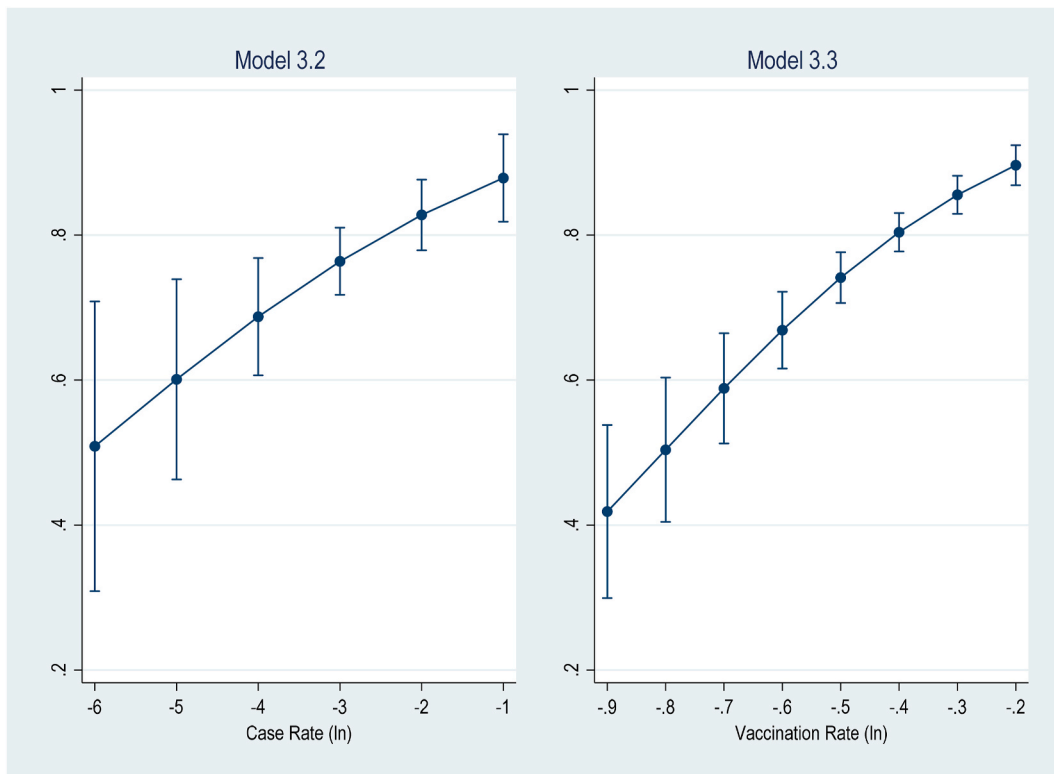


Fig. 3. Estimated Odds of becoming Fully Vaccinated predicted by Country-Level Factors.

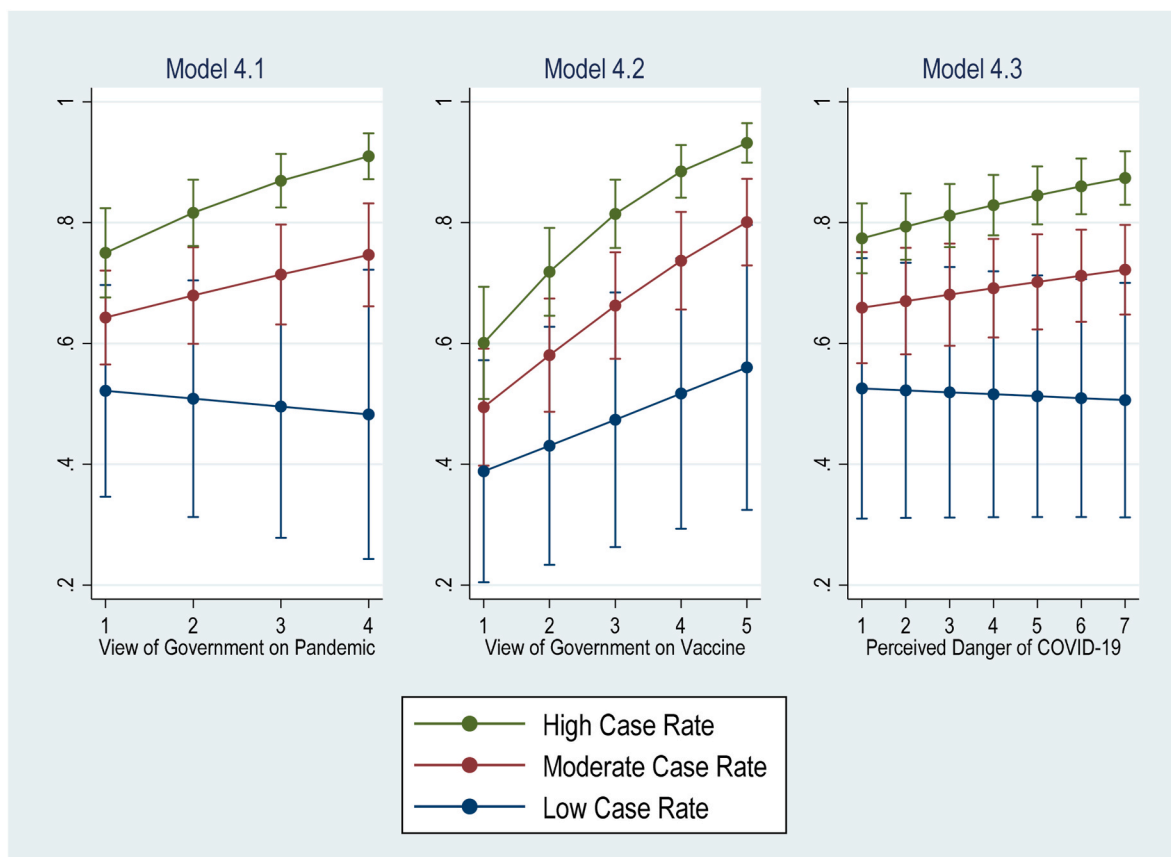


Fig. 4. Estimated Odds of becoming Fully Vaccinated predicted by Cross-level Interactions between Individual Factors and Country Case Rate.

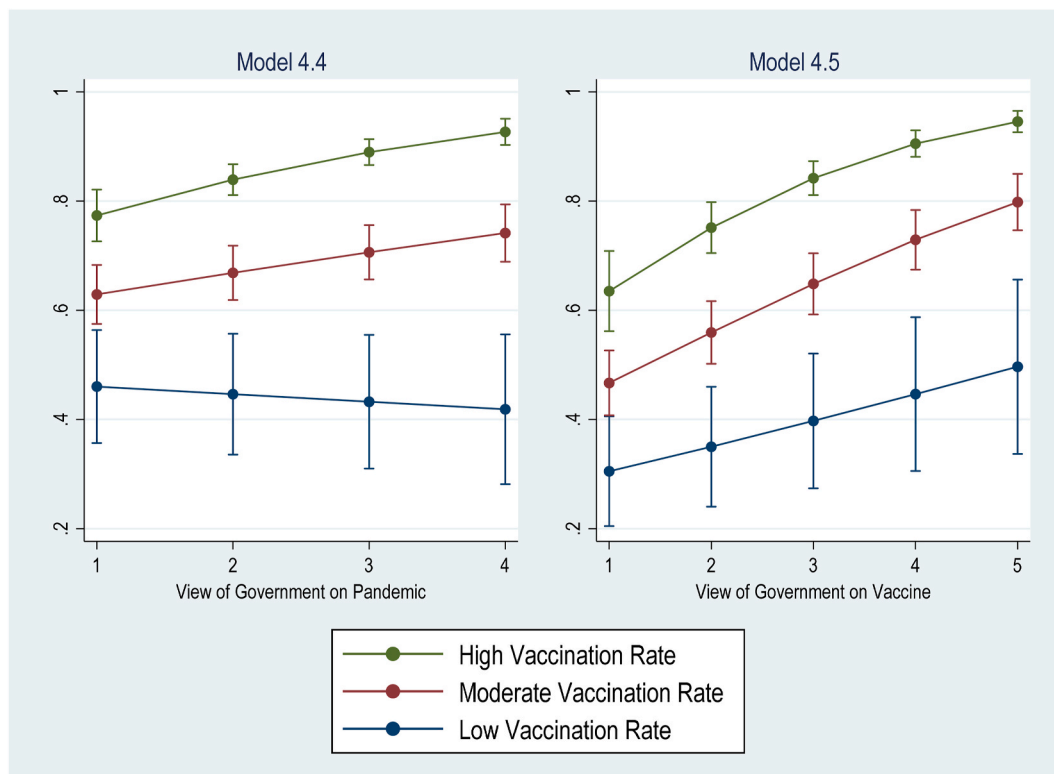


Fig. 5. Estimated Odds of becoming Fully Vaccinated predicted by Cross-level Interactions between Individual Factors and Country Vaccination Rate.

cross-level interactions are identified as people are more likely to become fully vaccinated if they approve of the government’s performance, perceive that the virus is dangerous, and also reside in countries with higher case and vaccination rates.

Existing research focused on vaccine uptake and its predictors for individual countries such as the United States (Szilagyi et al., 2021) and countries in Europe (Seddig et al., 2022) or Asia (Sasaki et al., 2022). One’s decision to get the COVID-19 vaccine is affected by sociodemographic characteristics, health conditions, and political orientation (Wang et al., 2021). Compared to those studies focused on single countries, this study complements the literature and provides cross-national evidence regarding the COVID-19 vaccine uptake. Methodologically, one prominent feature is the behavior of getting fully vaccinated is highlighted rather than the intention/willingness to take or the acceptance of the vaccine. The vaccine uptake behavior is a more accurate representation of one’s attitude toward the vaccine. Another feature is that the predictors include both individual and country level factors. Findings show significant predictors at both levels and interactions across levels. The successful control of this unprecedented public health crisis relies on how people around the world are vaccinated promptly. Different populations under various contexts might assess and react to the pandemic dissimilarly. Therefore, knowledge of the profiles of people who have become fully vaccinated or not provides essential information to leverage underlying factors and align human behaviors with scientific recommendations.

Based on the findings, it is critical to advertise the government’s efforts and emphasize the vaccine’s efficacy, which can counter the hampering effects of misinformation. Alerting populations to the virus’s risks and highlighting the benefits of population-wide vaccination against COVID-19 is also helpful. This concerted endeavor is multifaceted and must be addressed simultaneously at global, national, and local levels. Communications about vaccination urgency can be tailored towards populations hesitant to take the vaccine, including younger adults and people from countries with lower case and vaccination rates. Meanwhile, according to results in Fig. 1, more efforts to promote

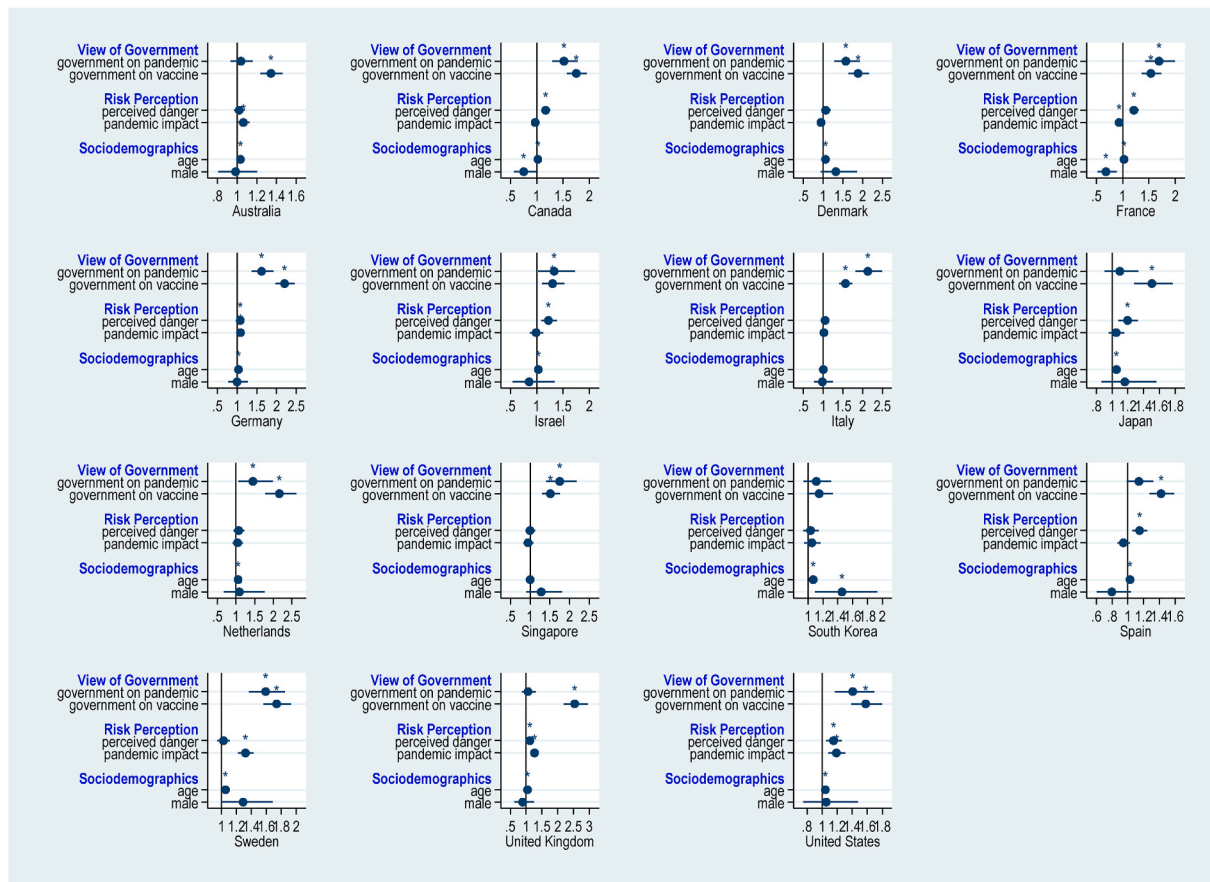
vaccination campaigns should target countries such as Australia, Japan, South Korea, and the United States, where only around half of the respondents said they had been fully vaccinated.

This study has limitations and research on this topic calls for more inquiries. First, the data used for analyses was collected in September 2021. With the ups and downs of COVID-19 cases and more information about different variants, one’s decision to be fully inoculated will likely be affected. Thus, future studies should continue monitoring the dynamics of public vaccination status or booster uptake using the latest data (Hao, 2022; Lennon et al., 2022). Second, the current study was constrained to 15 high-income countries. While economic affluence is a shared feature, the heterogeneity among these countries might affect the analyses. Subsequent research might consider better controlling that heterogeneity when appropriate measurements are available. To establish a global vaccination program, it is essential that middle- and low-income countries also obtain estimates of their public’s attitude toward getting the COVID-19 vaccine (Leach et al., 2022; Patwary et al., 2022). A comparison of the predictors’ effects on people from different groups of countries will also be meaningful for designing targeted COVID-19 policies. After the lack of access issue is addressed with an increasing number of doses trickling in, resistance to getting vaccinated mustn’t be another hurdle that delays attaining herd immunity. Third, in addition to the factors included in the present study, additional research needs to consider other factors that influence one’s vaccine uptake when data are available. For example, personal experience with the virus, the possibility to work from home, and vaccine framing plus economic recovery, monetary incentives, and vaccine pass at the collective level might all shape the mindsets of people who are hesitant to take the vaccine (Campos-Mercade et al., 2021; Caserotti et al., 2022; Saban et al., 2021).

Data availability

Data will be made available on request.

Appendix 1. Effects of Individual-level Predictors on Public Decision of becoming Fully Vaccinated by Country



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