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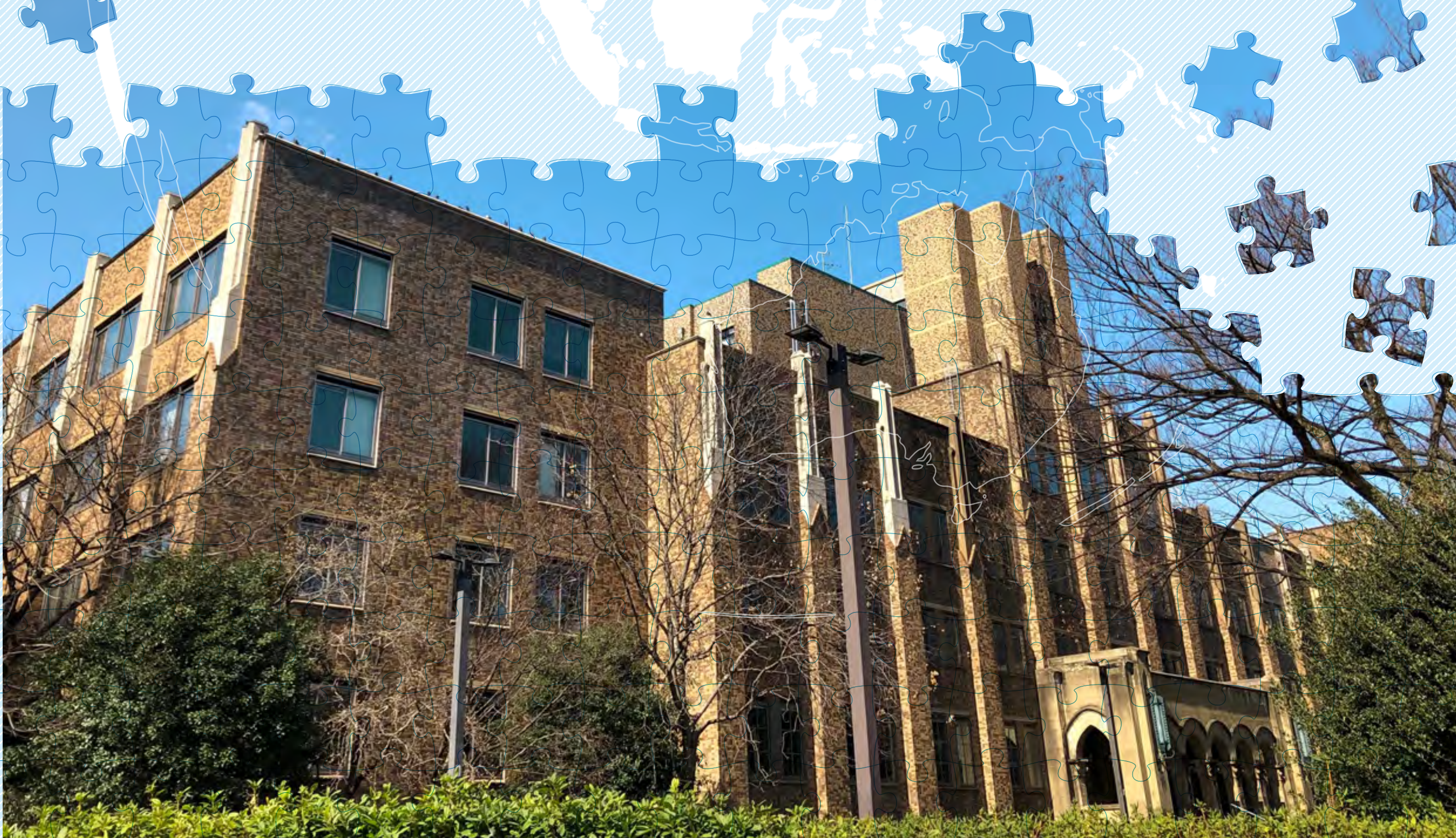
Updated beliefs and shaken confidence

Evidence from vaccine hesitancy caused by experiencing "COVID arm"



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Name
Taiyo Fukai, Keisuke Kawata, Masaki Nakabayashi

Updated beliefs and shaken confidence

Evidence from vaccine hesitancy caused by experiencing "COVID arm"*

Taiyo Fukai† Keisuke Kawata‡ Masaki Nakabayashi§

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†Faculty of Humanities and Social Sciences, University of Tsukuba. E-mail: fukai@e.u-tokyo.ac.jp

‡Institute of Social Science, The University of Tokyo. E-mail: keisukekawata@iss.u-tokyo.ac.jp

§Institute of Social Science, The University of Tokyo. E-mail: mn@iss.u-tokyo.ac.jp

Ethical Review

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Declaration of interest statement

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Disclosure Statement
Taiyo Fukai, Keisuke Kawata and Masaki Nakabayashi

The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

Author statement

Keisuke Kawata and Masaki Nakabayashi designed and conducted the survey. Keisuke Kawata implemented the estimates and created a survey note. Taiyo Fukai and Masaki Nakabayashi wrote the first draft based on the survey note created by Keisuke Kawata. Taiyo Fukai, Keisuke Kawata, and Masaki Nakabayashi jointly examined the entire draft, edited it, and finalized it for submission.

Informed consent

The authors, namely, Taiyo Fukai, Keisuke Kawata, and Masaki Nakabayashi, obtained informed consent from all participants of the survey by designing the survey such that, on the opening page, the survey described itself, requested informed consent, and did not allow a respondent to participate in the survey unless the respondent gave informed consent.

Data availability

The datasets generated by the survey research and analyzed during the current study will be publicly available after cleaning at the Center for Social Research and Data Archives, Institute of Social Science, The University of Tokyo (https://csrda.iss.u-tokyo.ac.jp/english/). Before they become publicly available at the institution, they are available from the corresponding author, Masaki Nakabayashi, upon request.

Key points

Question

Do updates to beliefs about vaccines affect confidence in vaccination?

Findings

In a panel survey in February 2021 and March 2022 in Japan, before and after COVID-19 vaccines were administered to the public in Japan, out of 15,000 respondents of the first wave, 9,668 responded to the second wave, we used “COVID arm” symptoms as our instrument. Experiencing such symptoms significantly reduced confidence in the safety of vaccination but did not the acknowledged importance of vaccination in general.

Meaning

Updates to beliefs affected confidence in vaccination. Acknowledgment of general vaccination importance was likely to have factored in the uncertainty.

Abstract

Importance

Public health depends on both medical treatment development and the public's willingness to take such treatment.

Objective

To determine whether having experienced delayed localized hypersensitivity reactions to COVID-19 vaccines, i.e., "COVID arm" symptoms affect confidence in the safety of vaccination, willingness to take COVID-19 vaccines, and the acknowledgement of the importance of vaccination, and also confidence in science.

Design

We implemented a survey in February 2021 and March 2022 in Japan, before and after COVID-19 vaccines were administered to the public in Japan, and we used "COVID arm" symptoms, which are independent of one's prior confidence in vaccination, as our instrument.

Setting

We conducted a panel survey on internet.

Participants

Out of the non-probability sample of 15,000 respondents in the first wave in February 2021, 9,668 responded to the second wave conducted in March 2022.

Intervention

We used " COVID arm" symptoms as a natural experiment conditional on the background characteristics of the respondents.

Main Outcomes and Measures

Main outcomes are whether having experienced "COVID arm" symptoms affected 1) confidence in the safety of vaccination; 2) willingness to take the next dose of COVID-19 vaccines, 3) acknowledgment of the importance of vaccination, and 4) confidence in science. Measures are marginal means of the probability of a positive reaction to each question.

Results

Experiencing "COVID arm" symptoms significantly lowered confidence in the safety of vaccination by 3.4 percentage points and the probability of taking a second and third dose of COVID-19 vaccine by 1.2 and 3.4 percentage points, respectively. Adverse impacts were observed regardless of prior confidence in vaccination. Experiencing such symptoms affected neither the acknowledged importance of vaccination nor confidence in science.

Conclusions and relevance

Updates to beliefs about side effects affected confidence in the safety of vaccination. Acknowledgment of vaccination importance and general confidence in science are likely to have factored in the uncertainty and to be tolerant of updates to one's beliefs about side effects. Belief updates of specific treatments had asymmetric impacts on the treatment and medicine in general.

Trial Registration

The design of the survey was preregistered with the American Economic Association's RCT Registry [1].

Keywords Belief updates | "COVID arm" symptoms as instrument | Confidence in vaccination | Recognized importance of vaccination | Confidence in science.

1 Introduction

General confidence in and perceived risk of technologies are associated [2]. Public health depends on the development of medical treatments and also confidence in the developed treatments, which would affect the public's willingness to take the treatments. Public confidence in medical treatment is likely to depend on prior beliefs about the benefits and risks of the treatment. Events that alter such beliefs might affect the public's confidence in medicine. However, it is difficult to observe this change systematically and hence to identify the causality of certain events regarding belief updates and changes in confidence in medicine under ordinary circumstances.

The COVID-19 pandemic provided unusual circumstances in which we can test hypotheses about such changes. First, since COVID-19 vaccines were a new treatment for everyone, the uncertainty surrounding the related effects and side effects was higher [3], provided that higher expected probabilities of side effects of COVID-19 vaccines would discourage vaccination [4, 5, 6, 7, 8, 7, 9, 10, 11, 12, 13]. Second, a substantial subset of recipients experienced delayed localized hypersensitivity reactions to COVID-19 vaccines [14, 15]; such reactions, collectively referred to as "COVID arm" have been objectively observed. Additionally, "COVID arm" symptoms are likely to be independent of the vaccine recipients' beliefs about vaccination, science, and authority prior to getting vaccinated, conditional on possible confounders such as the recipients' background characteristics. To investigate whether the uncomfortable event of vaccination has affected the public's confidence in vaccination, authorities' licensing process for vaccines, and science in general through belief updates, we conducted a panel survey in Japan in February 2021, when COVID-19 vaccines were not yet administered to the public in Japan, and in March 2022, when the first and second doses were available to anyone. In the first and second waves, we asked the same questions regarding confidence in vaccination and the vaccine licensing authority in Japan. In the second wave, we also asked the respondents about confidence in science in general.

Our data and findings are novel first in the sense that we asked the same respondents about their beliefs regarding vaccination both before and after getting vaccinated against COVID-19 and second because we used a side effect of vaccination, namely, "COVID arm" symptoms, which were perceived by the respondents separately from their beliefs about vaccines, as our instrument.

2 Our aim

Different beliefs about vaccines would lead to different levels of confidence in vaccination and hence to a range of willingness to get vaccinated. Using panel data from Germany, Schmelz and Bowles showed that one factor associated with opposition to COVID-19 vaccination is beliefs about the efficacy of the vaccines [16]. Using data from the UK, Freeman et al. found that the provision of information about vaccine efficacy reduces vaccine hesitancy [17]. By Southeast Asian data, Duong and Antriyandarti also found that respondents who were more informed about efficacy were less vaccine-hesitant [18]. Using extensive panel data from 12 countries, Algan et al. also found that confidence in science is significantly associated with attitudes toward vaccinations [19].

These contributions are substantial. However, as Schmelz and Bowles admitted, we cannot rule out the possibility of reverse causality, in which people may change their attitudes toward vaccination to justify a change in their own opinions about vaccination [16].

Thus, our research question was whether experiencing an unexpected side effect from COVID-19 vaccines, which implies an update to belief after the vaccines' side effects, affected confidence in vaccination. Specifically, we used the occurrence of "COVID arm" symptoms as our instrument to identify the causality of experiences that can alter beliefs about vaccines on confidence in vaccination.

3 Method

3.1 Panel survey

In the first and second waves, we recruited a nonprobability sample of 15,000 Japanese adults through a survey company, Rakuten Insight Ltd.[1] The first wave took place from February 17, 2021, to March 4, 2021, and the median response time was 7 minutes. The second wave took place from March 7, 2022, to March 22, and the median response time was 8 minutes. In both waves, we asked respondents about their confidence in vaccination, their confidence in the vaccine licensing authority's process, and their recognition of the importance of vaccination. Out of the 15,000 respondents in the first wave, 9,668 also participated in the second wave, who formed our sample.

In the second wave, we asked whether the participants had taken the first and second doses of the COVID-19 vaccine, whether they had experienced "COVID arm" symptoms, whether they had already taken a third dose of the vaccine and if not, whether they wanted to do so. We also asked about their confidence in science and scientists in general.

In both waves, we asked about the following demographic, socioeconomic, and political background characteristics: age, gender, marital status, children, siblings, prefecture of residence, working status, highest educational degree, personal income, household income, self-perceived social status, party support, self-perceived degree of right-leaning

[1] Detailed information about Rakuten Insight's respondent pool is available from its website. https://insight.rakuten.co.jp/download/PanelProfile_EN.pdf and https://insight.rakuten.co.jp/download/PanelCharacteristicSurveyEN.pdf.

political beliefs, and degree of dissatisfaction with current politics. In the second wave, we also asked whether the participants had any chronic diseases.

3.2 A natural experiment conditional on background characteristics

When we designed this survey, we assumed that the occurrence of "COVID arm" symptoms would be independent of recipients' beliefs about vaccines, the vaccine licensing authority in Japan, and science in general. After studying the data we collected, we found that the occurrence of "COVID arm" symptoms was associated with certain background characteristics and that confidence in vaccination, the vaccine licensing authority, and science were also associated with certain background characteristics.

In summary, our data indicated that "COVID arm" symptoms and beliefs about vaccines, the vaccine licensing authority in Japan, and science in general were conditionally independent given the background characteristics examined, which did not change before or after experiencing "COVID arm" symptoms. Therefore, we analyzed the data of respondents who took COVID-19 vaccines, controlling for background characteristics, as a natural experiment.

3.3 Treatment and predicted outcomes

Between the first wave in February 2021 and the second wave in March 2022, some of the vaccine recipients experienced "COVID arm" symptoms. We considered the occurrence of "COVID arm" symptoms as a treatment. We predicted that "COVID arm" symptoms, which caused an unexpected increase in the cost of receiving medical treatment, would affect beliefs about vaccines and that the belief updates would affect confidence in vaccination, the vaccine licensing authority, and science in general.

3.4 Identification and estimation strategy

Consider potential outcome $Y_{v^l,i}(D_i)$ regarding confidence in vaccination, where D_i denotes whether the person experienced "COVID arm" symptoms such that

$$D_i = \begin{cases} 1 & \text{if respondent } i \text{ experienced "COVID arm" symptoms,} \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

For $Y_{v^l,i}(D_i)$, l denotes

1. Whether respondent i considered vaccination in general to be safe,
2. Whether respondent i was confident in the vaccine licensing process by the Japanese authority, the Ministry of Health, Labour and Welfare,
3. Whether respondent i acknowledged the importance of vaccination in general,
4. Whether respondent i took a second dose of the COVID vaccine,
5. Whether respondent i took or wanted to take a third dose of the COVID vaccine,

such that

$$Y_{v^l,i}(D_i) = \begin{cases} 1 & \text{if respondent } i \text{ answers "yes",} \\ 0 & \text{otherwise,} \end{cases} \quad (2)$$

for $l = 1, ..., 5$.

As a supplementary survey, we asked the respondents about their general confidence in science in general in the second wave such that

$$Y_{s,i}\left(D_i\right) = \begin{cases} 1 & \text{if respondent } i \text{ was strongly confident in science,} \\ 2 & \text{if respondent } i \text{ was moderately confident in science,} \\ 3 & \text{if respondent } i \text{ was not confident in science very much,} \\ 4 & \text{if respondent } i \text{ was not confident in science at all.} \end{cases} \tag{3}$$

Then, we obtained three outcome variables such that

$$\begin{aligned} Y_{s^1,i}\left(D_i\right) &= \begin{cases} 1 & \text{if } \; Y_{s,i}\left(D_i\right) = 1, \\ 0 & \text{otherwise,} \end{cases} \\ Y_{s^2,i}\left(D_i\right) &= \begin{cases} 1 & \text{if } \; Y_{s,i}\left(D_i\right) \leq 2, \\ 0 & \text{otherwise,} \end{cases} \\ Y_{s^3,i}\left(D_i\right) &= \begin{cases} 1 & \text{if } \; Y_{s,i}\left(D_i\right) \leq 3, \\ 0 & \text{otherwise.} \end{cases} \end{aligned} \tag{4}$$

Thus, the value of our interest is the expected difference in marginal means between when having experienced "COVID arm" symptoms, $D_i = 1$ and when not, $D_i = 0$ such that

$$\tau\left(\boldsymbol{x}\right) = E\left[Y_{j,i}\left(1\right) - Y_{j,i}\left(0\right) \middle| \boldsymbol{X}_i = \boldsymbol{x}\right], \tag{5}$$

where $j \in \{v^1, v^2, v^3, v^4, v^5, s^1, s^2, s^3\}$ and $\boldsymbol{X}_i$ denote the background characteristics of respondent i.

As discussed in subsection 3.2, "COVID arm" symptoms D_i and confidence in vaccination, the vaccine licensing authority in Japan, and science $Y_{j,i}$ satisfy the unconfoundedness assumption conditional on background characteristics $\boldsymbol{X}_i$ such that

$$D_i \perp\!\!\!\perp \left[Y_{j,i}\left(0\right), Y_{j,i}\left(1\right)\right] \big| \boldsymbol{X}_i.$$

Therefore, we identified equation (5) as a causal effect of "COVID arm" symptoms D_i on the confidence in vaccination and the vaccine licensing authority $Y_{v,i}$, and confidence in science $Y_{s,i}$, given $\boldsymbol{X}_i$.

We wanted to obtain the average treatment effect as the augmented inverse propensity weight estimator of $\tau\left(\boldsymbol{x}\right)$ and its best linear predictor. To construct the augmented inverse propensity weighted (AIPW) estimator, we estimated $\tau\left(\boldsymbol{x}\right)$ of equation (5) by a causal forest algorithm, applying a partial linear model using a double/debiased machine learning algorithm [20, 21, 22], and we estimated the outcome and propensity by the random forest algorithm [23]. Last, we regressed the AIPW score estimates on $\boldsymbol{X}_i$ by OLS to obtain the best linear predictor of $E\left[\tau\left(\boldsymbol{x}\right)\right]$. All algorithms we implemented are included in the *grf* package for R [24].

4 Descriptive statistics

4.1 Progress in COVID-19 vaccination progress

The status of vaccination in Japan is summarized as follows. First, Pfizer's vaccine was approved by the Ministry of Health, Labour, and Welfare on February 14, 2021, and the priority vaccination of healthcare workers and others began on February 17, 2021. On April 12, 2021, the prioritized vaccination of approximately 36 million older adults began; at this time, vaccination by municipal governments also began. The Ministry approved the Moderna and AstraZeneca vaccines on May 21 of the same year. The first round of vaccination started in earnest around May 2021, with the number of daily doses peaking between July and August of the same year. According to the Vaccination Record System, Digital Agency, Government of Japan, the first dose intake rate from February 17 to March 4, 2021, the time of the first survey, was almost 0%. The first intake rate at the time of the second survey, from March 7 to March 22, 2022, was just under 80%.[2]

4.2 Overview

Descriptive statistics of our sample's background characteristics $\boldsymbol{X}_i$ for $i = 1 \ldots 9,668$ are presented in Table A1 in the supplemental appendix. Out of 9,668 respondents who participated in both waves, the 8,321 respondents who received a first dose formed our primary sample. The Japanese government has supplied both the Pfizer and Moderna vaccines for its domestic vaccination program. In our sample, recipients of both the Moderna vaccine and the Pfizer vaccine reported experiencing "COVID arm" symptoms. The self-reported "COVID arm" symptoms in our sample included both the severe symptoms triggered often by the Moderna vaccine and less severe symptoms.

Respondents who had received a first dose of a COVID-19 vaccine as of March 2022 accounted for 86.0% of our sample, those who received a second dose accounted for 84.0%, and those who received or wanted to take a third dose accounted for 32.2%. Among those who did not experience "COVID arm" symptoms during the first dose, 98% took a second dose; among those who experienced the symptoms during the first dose, 97% took a second dose. Furthermore, 38% of those who did not experience the symptoms took or wanted to take a third dose, while 37% of those who experienced the symptoms took or wanted to take a third dose, as of February 2022. Therefore,

[2] https://info.vrs.digital.go.jp/ Accessed on July 16, 2022.

experiencing “COVID arm” symptoms was associated with a reduction in the uptake of a second dose and the uptake of or willingness to take a third dose by 1 percentage point each time.

4.3 Balancing covariates

Figure A1 in the supplemental appendix presents a regression of the probability of experiencing “COVID arm” symptoms on the four primary background characteristics: age, gender, vaccine type, and chronic disease status. As reported [14, 15, 25], experiencing “COVID arm” was strongly associated with taking the Moderna vaccine. Additionally, female respondents were more likely to report “COVID arm” symptoms than male respondents as having been reported, and younger people were less likely to report such symptoms than older people, as having been reported [26, 27]. Having a chronic disease showed a positive but small association with experiencing “COVID arm” symptoms. Furthermore, as Figure A2 after adjusting the sample according to these four covariates in the supplemental appendix shows, associations of background characteristics with “COVID arm” symptoms were beyond the four primary covariates.

Figure A3 in the supplemental appendix presents the means of “COVID arm” symptoms predicted by background characteristics $\boldsymbol{X}_i$ for two groups subsampled by whether they experienced the symptoms. Respondents who experienced the symptoms are shown to have a higher predicted median probability of the symptoms. Meanwhile, Figure A3 shows that the mean of either subsample approaches neither 1 nor 0, which allowed us to balance the sample by weighting $\boldsymbol{X}_i$.

Therefore, our estimates of $\tau(\boldsymbol{x})$ in equation (5) deployed augmented inverse propensity weighting to estimate $E[\tau(\boldsymbol{x})]$. We also adopted a conservative approach for estimating the confidence intervals, as suggested by Holm [28].

5 Results

5.1 Confidence in vaccination

Figure 1 presents the estimated average treatment effects $E[\tau(\boldsymbol{x})]$ characterized by equation (5). The scale of the horizontal axis is the predicted change, due to experiencing "COVID arm" symptoms, in probability of having taken or wanting to take a third dose, having taken a second dose, considering vaccination in general as safe, acknowledging vaccination as being important, and being confident in the vaccine licensing authority.

Figure 1 demonstrates that experiencing "COVID arm" symptoms significantly decreased confidence in the safety of vaccines by 3.4 percentage points. Additionally, experiencing "COVID arm" symptoms significantly reduced the probability of taking a second dose of COVID-19 vaccines by 1.2 percentage points and the probability or willingness to take a third dose by 4.3 percentage points. "COVID arm" symptoms negatively but insignificantly affected confidence in the vaccine licensing authority. However, "COVID arm" symptoms barely affected the acknowledgement of the importance of vaccination in general.

In summary, updates of beliefs about vaccine side effects due to experiencing "COVID arm" symptoms adversely affected participants' confidence in the safety of vaccination and their probability of taking a second dose and taking or wanting to take a third dose. However, the change in the perceived risk of side effects did not affect the acknowledged importance of vaccination. We interpreted this result as indicating that the recognition of the vaccination's importance had already factored in uncertainty regarding vaccination, so this recognition tolerant to belief updates regarding the estimable risks of side effects.

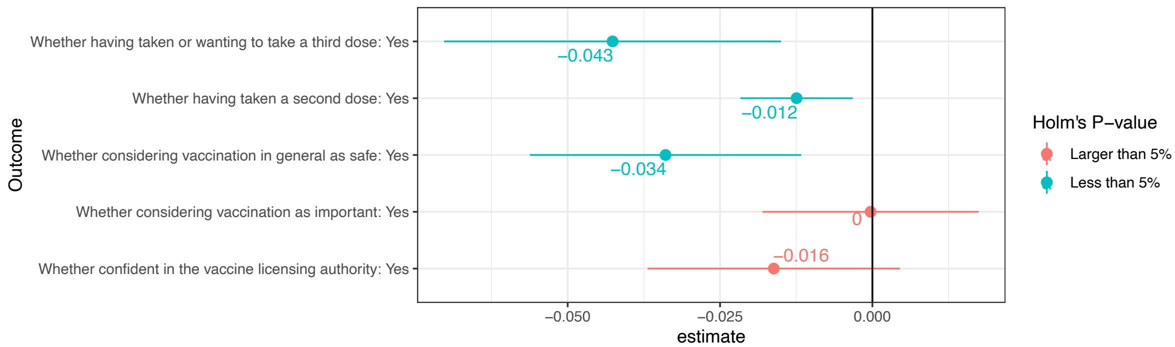

Figure 1: Impact of "COVID arm" symptoms on confidence in vaccination.

Notes: According to equations (2) and (5), the estimates indicate the change in the predicted probability of taking a second and taking or wanting to take a third dose. The confidence interval was adjusted by the Bonferroni method, in addition to the p-values adjusted by the Holm method [28]. Point estimates of confidence intervals are presented in Table A2 in the supplemental appendix.

Figure A4 and Figure A5 in the supplemental appendix present the approximated conditional average treatment effects on the confidence in vaccination and the probability of taking a second dose and of taking or wanting to take a third dose by linearly regressing those outcomes on the background characteristics. No element except for employer size had a significant impact on the treatment effect of "COVID arm" symptoms, which means that the treatment effects were found across background characteristics.

Furthermore, Figures A4 and A5 demonstrate that the treatment effect of "COVID arm" symptoms was found regardless of the prior level of confidence in vaccination and the vaccine licensing authority before getting vaccinated. Also irrelevant to treatment effects were prior indications of vaccine hesitancy before receiving COVID-19 vaccines, such as postponing vaccination instead of doctors' recommendations. The adverse impacts of "COVID arm" symptoms on confidence in vaccination did not depend on prior confidence in vaccination or vaccine hesitancy but did depend on belief updates regarding the side effects of vaccines.

5.2 Confidence in science

In a second survey wave conducted in March 2022, we also asked the respondents about their confidence in science in general, as described by equation (4), as a supplementary study. Figure 2 presents $\tau(\boldsymbol{x})$ on the confidence in science in general, calculated by equation (5). The impact of "COVID arm" symptoms on one's confidence in science in general was weak. Only the probability of being "strongly confident in science," calculated by equation (4), was weakly significantly lowered by experiencing "COVID arm" symptoms. We interpreted this result in parallel to the insignificant result for the acknowledged importance of vaccination in Figure 1. That is, confidence in science in general had already factored in the chance of uncertain outcomes following vaccination and was thus tolerant of belief updates regarding risks estimable associated with vaccination.

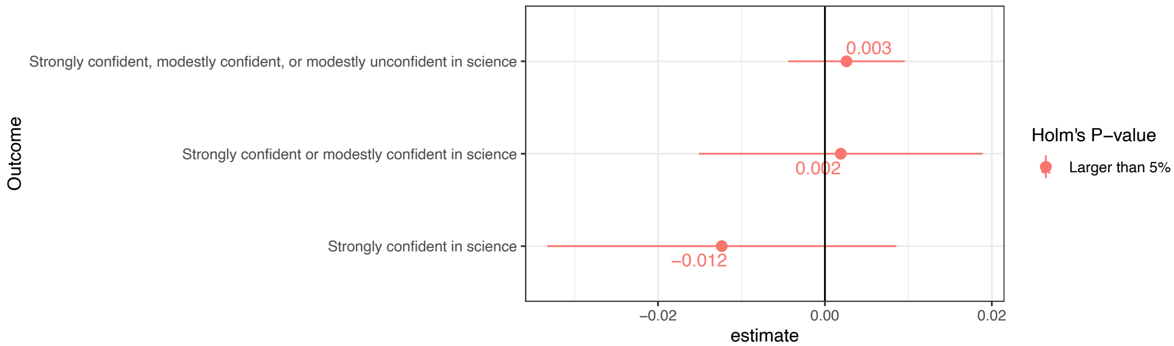

Figure 2: Impacts of "COVID arm" symptoms on confidence in science.

Notes: Point estimates of confidence intervals are presented in Table A3 in the supplemental appendix.

Additionally, Figure A6 in the supplemental appendix presents the approximated conditional average treatment effects by linearly regressing the outcome on background characteristics. The results show the insignificant effect of experiencing "COVID arm" symptoms on general confidence in science across background characteristics.

6 Conclusion

In February 2021 and March 2022, we asked the same respondents about their confidence in vaccination and in March 2022 about whether they had experienced "COVID arm" symptoms. We found that experiencing "COVID arm" symptoms significantly decreased their confidence in the safety of vaccination and the probability of taking a second dose and taking or wanting to take a third dose of COVID-19 vaccines. Adverse impacts were found regardless of the prior confidence in vaccination.

Meanwhile, experiencing "COVID arm" symptoms did not affect the acknowledged general importance of vaccination and general confidence in science. We interpret these irrelevance results as being because these recognitions had already factored in uncertainties such that the recognitions were tolerant to belief updates regarding risks now estimable of side effects.

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Supplemental appendix

SA 1 Descriptive statistics

Table A1 presents descriptive statistics of the respondents' background characteristics. We first classified the sample into respondents who took a first dose of COVID-19 vaccines and those who did not. Next, we partitioned the respondents who took a first dose into those who experienced "COVID arm" symptoms and those who did not.

We found differences between vaccine recipients and those who had not taken a first dose as of March 2022 in terms of income levels, age, educational achievement, and political beliefs. On average, vaccine hesitant individuals were younger and less educated, more likely to be unmarried, and more likely to be politically independent than vaccine recipients. A striking difference between the vaccine recipients and those who were vaccine hesitant was in the evolution of their confidence in the vaccination. Among those who had taken the first dose of COVID-19 vaccine as of March 2022, 25% were not confident in vaccination in February 2021, but the percentage fell to 18% in March 2022. The experience of taking the COVID-19 vaccine was accompanied by a rise in confidence in vaccination. In contrast, among those who had not taken the first dose of COVID-19 vaccine as of March 2022, 56% were not confident in vaccination in February 2021, and the percentage climbed to 70% in March 2022. Thus, the division between vaccine recipients and vaccine hesitant individuals in terms of confidence in vaccination deepened. However, the deepening of this division in Japan that existed before vaccine rollout is not the focus of our work. Our interest is in how "COVID arm" symptoms, as an unexpected shock, affected beliefs about vaccination among recipients of the first dose of the COVID-19 vaccine. Therefore, we used the 8,321 respondents who received a first dose and participated in both the first and second waves as our primary sample.

Table A1. Descriptive statistics.

Characteristics	Have taken first dose of COVID-19 vaccine		Have not taken first dose of COVID-19 vaccine
	COVID arm: Yes N = 3,214[1]	COVID arm: No N = 5,098[1]	N = 1,356[1]
Confident in science, Mar 2022			
Strongly confident	585 (18%)	1,056 (21%)	160 (12%)
Confident to some extent	2,248 (70%)	3,465 (68%)	869 (64%)
Not confident very much	327 (10%)	489 (9.6%)	227 (17%)
other[2]	54 (1.7%)	88 (1.7%)	100 (7.4%)
Confident in vaccination in general, Mar 2022			
Confident	2,477 (77%)	4,160 (82%)	384 (28%)
Not confident	715 (22%)	909 (18%)	954 (70%)
other[2]	22 (0.7%)	29 (0.6%)	18 (1.3%)
Thinking about vaccination important in general, Mar 2022			
Important	2,854 (89%)	4,551 (89%)	531 (39%)
Not important	286 (8.9%)	440 (8.6%)	786 (58%)
other[2]	74 (2.3%)	107 (2.1%)	39 (2.9%)
Confident in vaccination licensing by Ministry of Health, Labour and Welfare, Mar 2022			
Confident	2,631 (82%)	4,271 (84%)	409 (30%)
Not confident	553 (17%)	790 (15%)	919 (68%)
other[2]	30 (0.9%)	37 (0.7%)	28 (2.1%)
Have taken first dose of COVID-19 vaccine, Mar 2022			
Yes	3,214 (100%)	5,098 (100%)	0 (0%)
No	0 (0%)	0 (0%)	1,277 (94%)
other[2]	0 (0%)	0 (0%)	79 (5.8%)
Have taken second dose of COVID-19 vaccine, Mar 2022			
Yes	3,113 (97%)	5,008 (98%)	0 (0%)
Do not remember	56 (1.7%)	57 (1.1%)	1,356 (100%)
other[2]	45 (1.4%)	33 (0.6%)	0 (0%)
Have taken third dose of COVID-19 vaccine, Mar 2022			
Yes	1,174 (37%)	1,939 (38%)	0 (0%)
No	1,911 (59%)	3,028 (59%)	0 (0%)
Do not remember	129 (4.0%)	131 (2.6%)	1,356 (100%)
Will take third dose of COVID-19 vaccine, Mar 2022			
Will take	1,453 (45%)	2,427 (48%)	0 (0%)
Have not decided	345 (11%)	462 (9.1%)	0 (0%)
Do not know	1,306 (41%)	2,076 (41%)	1,356 (100%)
other[2]	110 (3.4%)	133 (2.6%)	0 (0%)
Which type of COVID-19 vaccine as of Mar 2022			
Pfizer	2,201 (68%)	4,038 (79%)	0 (0%)
Moderna	922 (29%)	895 (18%)	0 (0%)
Do not remember	44 (1.4%)	66 (1.3%)	1,356 (100%)
other[2]	47 (1.5%)	99 (1.9%)	0 (0%)
Have contracted COVID-19, Feb 2021			
No	3,116 (97%)	4,943 (97%)	1,257 (93%)
other[2]	98 (3.0%)	155 (3.0%)	99 (7.3%)
Have taken any vaccines, Feb 2021			
Yes	1,624 (51%)	2,532 (50%)	443 (33%)
No	1,550 (48%)	2,497 (49%)	860 (63%)
other[2]	40 (1.2%)	69 (1.4%)	53 (3.9%)
Confident in vaccination, Feb 2021			
Trust	2,189 (68%)	3,577 (70%)	484 (36%)
Do not trust	869 (27%)	1,269 (25%)	753 (56%)
Do not know	156 (4.9%)	252 (4.9%)	119 (8.8%)
Consider vaccination important, Feb 2021			
Important	2,693 (84%)	4,269 (84%)	709 (52%)
Not important	372 (12%)	594 (12%)	506 (37%)
Do not know	149 (4.6%)	235 (4.6%)	141 (10%)
Trust in vaccine licensing by Ministry of Health, Labour and Welfare Feb 2021			
Trust	2,363 (74%)	3,803 (75%)	557 (41%)
Do not trust	603 (19%)	929 (18%)	604 (45%)
other[2]	248 (7.7%)	366 (7.2%)	195 (14%)
Whether have avoided vaccination due to concerns about risk or efficacy of			

vaccines, Feb 2021.			
Yes	569 (18%)	776 (15%)	429 (32%)
No	2,536 (79%)	4,146 (81%)	827 (61%)
other[2]	109 (3.4%)	176 (3.5%)	100 (7.4%)
Have postponed vaccination recommended by a doctor, Feb 2021			
Yes	264 (8.2%)	381 (7.5%)	192 (14%)
No	2,869 (89%)	4,581 (90%)	1,072 (79%)
other[2]	81 (2.5%)	136 (2.7%)	92 (6.8%)
Trust whose opinion regarding vaccination, Feb 2021			
Family or good friends	215 (6.7%)	311 (6.1%)	147 (11%)
Doctor	2,332 (73%)	3,798 (74%)	678 (50%)
Internet	309 (9.6%)	425 (8.3%)	227 (17%)
Other sources	284 (8.8%)	423 (8.3%)	216 (16%)
other[2]	74 (2.3%)	141 (2.8%)	88 (6.5%)
Think COVID-19 vaccination should be mandatory, Feb 2021			
Yes	1,591 (50%)	2,671 (52%)	295 (22%)
No	1,446 (45%)	2,152 (42%)	931 (69%)
Do not want to answer	157 (4.9%)	255 (5.0%)	123 (9.1%)
other[2]	20 (0.6%)	20 (0.4%)	7 (0.5%)
Think COVID-19 vaccines should be fully subsidized by the government, Feb 2021			
Yes	2,730 (85%)	4,393 (86%)	965 (71%)
No	373 (12%)	557 (11%)	281 (21%)
other[2]	111 (3.5%)	148 (2.9%)	110 (8.1%)
Gender			
Male	1,555 (48%)	2,955 (58%)	675 (50%)
Female	1,659 (52%)	2,143 (42%)	681 (50%)
other[2]	0 (0%)	0 (0%)	0 (0%)
Age, Feb 2021			
	49 (39, 59)	51 (42, 61)	45 (35, 53)
Prefecture of residence, Feb 2021			
Saitama	184 (5.7%)	278 (5.5%)	71 (5.2%)
Chiba	171 (5.3%)	272 (5.3%)	66 (4.9%)
Tokyo	470 (15%)	764 (15%)	176 (13%)
Kanagawa	297 (9.2%)	437 (8.6%)	114 (8.4%)
Aichi	206 (6.4%)	321 (6.3%)	92 (6.8%)
Osaka	245 (7.6%)	387 (7.6%)	134 (9.9%)
other[2]	1,641 (51%)	2,639 (52%)	703 (52%)
Marital status, Feb 2021			
Unmarried	858 (27%)	1,252 (25%)	570 (42%)
Married	2,067 (64%)	3,404 (67%)	660 (49%)
Divorced or bereaved	277 (8.6%)	417 (8.2%)	120 (8.8%)
other[2]	12 (0.4%)	25 (0.5%)	6 (0.4%)
Number of children, Feb 2021			
0	1,329 (41%)	2,013 (40%)	773 (57%)
1.	538 (17%)	814 (16%)	197 (15%)
2.	988 (31%)	1,638 (32%)	257 (19%)
3.	322 (10%)	536 (11%)	98 (7.3%)
4.	23 (0.7%)	73 (1.4%)	20 (1.5%)
5. or more	9 (0.3%)	18 (0.4%)	5 (0.4%)
other[2]	5	6	6
Working status, Feb 2021			
Employed	2,311 (72%)	3,703 (73%)	946 (70%)
Unemployed	894 (28%)	1,384 (27%)	408 (30%)
other[2]	9 (0.3%)	11 (0.2%)	2 (0.1%)
Employment type, Feb 2021			
Nonregular worker	625 (19%)	1,010 (20%)	259 (19%)
Regular worker	1,474 (46%)	2,315 (45%)	524 (39%)
Self-employed	180 (5.6%)	337 (6.6%)	138 (10%)
Do not know	906 (28%)	1,399 (27%)	412 (30%)
other[2]	29 (0.9%)	37 (0.7%)	23 (1.7%)
Job title, Feb 2021			
No title	1,359 (70%)	2,045 (67%)	571 (80%)
Team leader	86 (4.4%)	120 (3.9%)	24 (3.3%)
Assistant manager	197 (10%)	307 (10%)	59 (8.2%)
Manager	191 (9.9%)	364 (12%)	39 (5.4%)
Division manager	102 (5.3%)	221 (7.2%)	25 (3.5%)
no response[3]	1,279	2,041	638
Size of employer, Feb 2021			
1–4 employees	84 (4.4%)	119 (4.0%)	44 (6.2%)
5–29 employees	294 (16%)	481 (16%)	133 (19%)
30–99 employees	315 (17%)	486 (16%)	139 (19%)
100–499 employees	432 (23%)	695 (23%)	153 (21%)
500 or more	765 (40%)	1,222 (41%)	246 (34%)
Public servant	143 (7.0%)	216 (6.7%)	44 (5.8%)
no response[3]	1,324	2,095	641
no response[3]	1,181	1,879	597

Personal income, Feb 2021			
Less than 0.50 million yen	527 (16%)	681 (13%)	316 (23%)
0.50–0.99 million yen	263 (8.2%)	344 (6.8%)	118 (8.7%)
1.00–1.49 million yen	249 (7.8%)	369 (7.3%)	97 (7.2%)
1.50–1.99 million yen	161 (5.0%)	306 (6.0%)	93 (6.9%)
2.0–2.49 million yen	234 (7.3%)	393 (7.7%)	100 (7.4%)
2.50–2.99 million yen	188 (5.9%)	318 (6.3%)	93 (6.9%)
3.00–3.99 million yen	359 (11%)	610 (12%)	138 (10%)
4.00–4.99 million yen	340 (11%)	563 (11%)	133 (9.8%)
5.00 million yen or more	882 (28%)	1,496 (29%)	263 (19%)
no response[3]	11	18	5
Household income, Feb 2021			
2.00–2.49 million yen	159 (4.9%)	250 (4.9%)	80 (5.9%)
2.50–2.99 million yen	160 (5.0%)	251 (4.9%)	85 (6.3%)
3.00–3.99 million yen	355 (11%)	611 (12%)	164 (12%)
4.00–4.99 million yen	386 (12%)	640 (13%)	156 (12%)
5.00–5.99 million yen	377 (12%)	579 (11%)	143 (11%)
6.00–6.99 million yen	299 (9.3%)	453 (8.9%)	115 (8.5%)
7.00–7.99 million yen	291 (9.1%)	444 (8.7%)	113 (8.3%)
8.00–8.99 million yen	222 (6.9%)	371 (7.3%)	66 (4.9%)
9.00–9.99 million yen	191 (5.9%)	271 (5.3%)	48 (3.5%)
10 million yen or more	496 (15%)	781 (15%)	162 (12%)
other	278 (8.6%)	447 (8.8%)	224 (17%)
Highest degree, Feb 2021			
Junior high school	36 (1.1%)	51 (1.0%)	46 (3.4%)
High school	705 (22%)	1,186 (23%)	375 (28%)
Some college	722 (23%)	1,026 (20%)	339 (25%)
College	1,516 (47%)	2,501 (49%)	541 (40%)
Graduate School	228 (7.1%)	324 (6.4%)	53 (3.9%)
other[2]	7	10	2
Party support, Feb 2021			
Independent	1,769 (55%)	2,762 (54%)	864 (64%)
Opposition parties	650 (20%)	978 (19%)	242 (18%)
Ruling parties	787 (24%)	1,353 (27%)	245 (18%)
other[2]	8 (0.2%)	5 (¡0.1%)	5 (0.4%)
Satisfaction with current politics, Feb 2021			
Substantially satisfied	28 (0.9%)	66 (1.3%)	25 (1.9%)
Satisfied to some extent	338 (11%)	589 (12%)	95 (7.0%)
Neither satisfied nor dissatisfied	811 (25%)	1,313 (26%)	353 (26%)
Dissatisfied to some extent	903 (28%)	1,346 (26%)	293 (22%)
Substantially dissatisfied	1,125 (35%)	1,782 (35%)	585 (43%)
other[2]	9	2	5
Self-perceived degree of right-leaning political beliefs 0: Completely left; 10: Completely right			
	6.00 (6.00, 7.00)	6.00 (6.00, 7.00)	6.00 (6.00, 6.00)
other[2]	57	99	43
Self-perceived social status 1: Highest; 10: Lowest			
	6.00 (5.00, 8.00)	6.00 (5.00, 8.00)	6.00 (6.00, 8.00)
other[2]	37	61	35

[1] Number of responses (%) or median (interquartile range).
[2] Responses whose shares are 5% or less are summed and collectively referred to as "other".
[3] This question was irrelevant to the respondent or the respondent skipped the question. We allowed respondents to skip a question when they wanted to.

SA 2 Balancing covariates

Figure A1 presents standardized mean differences of the probability of experiencing the "COVID arm" between unadjusted and adjusted groups regarding four primary background characteristics: age, sex, Moderna vaccine recipient, and chronic disease status.

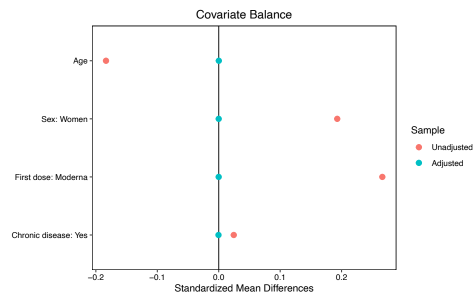

Figure A1: Covariate balances for primary variables.

Figure A2 presents linear regressions of whether respondents experienced "COVID arm" symptoms on background characteristics. Even after balancing the four primary background characteristics presented in Figure A1, the probability of experiencing "COVID arm" symptoms was associated with a wide range of other background characteristics, although the absolute values of the coefficients were smaller.

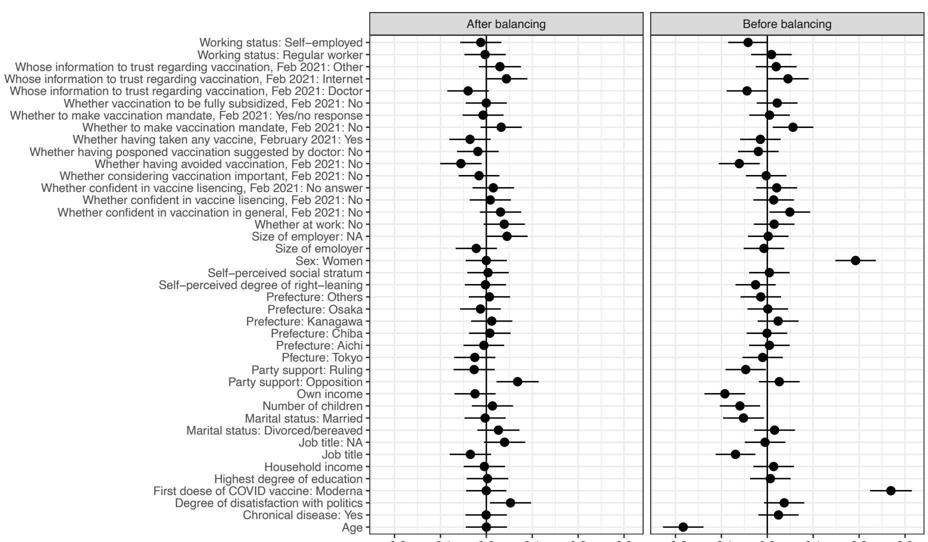

Figure A2: Covariate balances for all background characteristics.

We partitioned the sample into two subsamples depending on whether they actually experienced "COVID arm" symptoms and then predicted the means of "COVID arm" symptoms by background characteristics. As Figure A3shows, respondents who experienced “COVID arm” symptoms had a higher predicted median probability of “COVID arm” symptoms conditional on background characteristics .

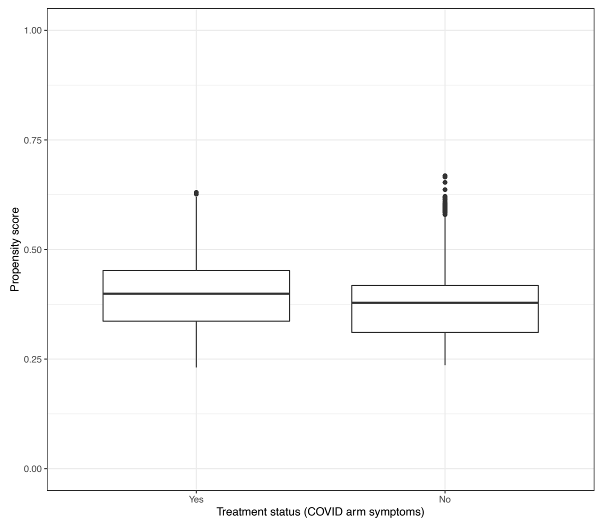

Figure A3: Predicted probability of experiencing “COVID arm” symptoms conditional on background characteristics.

SA 3 Point estimates of primary results

Table A2 presents point estimates of the results shown in Figure 1.

Table A2. Point estimates of Figure 1.

Outcome	Estimate	Std. error	Statistic	p value	confidence low	confidence high	N
Whether considering vaccination in general as safe: Yes	-0.03	0.01	-3.93	0.00	-0.06	-0.01	8311
Whether considering vaccination as important: Yes	-0.00	0.01	-0.04	0.97	-0.02	0.02	8311
Whether confident in the vaccine licensing authority: Yes	-0.02	0.01	-2.01	0.04	-0.04	0.00	8311
Whether having taken a second dose: Yes	-0.01	0.00	-3.47	0.00	-0.02	-0.00	8311
Whether having taken or wanting to take a third dose: Yes	-0.04	0.01	-3.97	0.00	-0.07	-0.01	8311

Table A3 presents the point estimates of the results shown in Figure 2.

Table A3. Point estimates of Figure 2.

Outcome	Estimate	Std. error	Statistic	p value	Confidence low	Confidence high	N
Strongly confident in science	-0.01	0.01	-1.42	0.16	-0.03	0.01	8311
Strongly confident or modestly confident in science	0.00	0.01	0.27	0.79	-0.02	0.02	8311
Strongly confident, modestly confident, or modestly unconfident in science	0.00	0.00	0.89	0.37	-0.00	0.01	8311

SA 4 Supplementary results

Figure A4 and Figure A5 present the approximated average treatment effects on the confidence in vaccination, the probability of taking a second dose, and the probability of taking or wanting to take a third dose, conditional on background characteristics $\boldsymbol{X}_i$. These effects are estimated by the best linear predictor, which regresses the average treatment effects on normalized $\boldsymbol{X}_i$, $E[\tau(\boldsymbol{x})|\boldsymbol{X}_i = \boldsymbol{x}] \approx \beta_0 + \boldsymbol{\beta} \times \boldsymbol{X}_i$, based on a debiased estimation method [29]. Except for the size of employer with the predicted treatment effects on confidence in the vaccine licensing authority, background characteristics were not significantly associated with the predicted treatment effects of "COVID arm" symptoms.

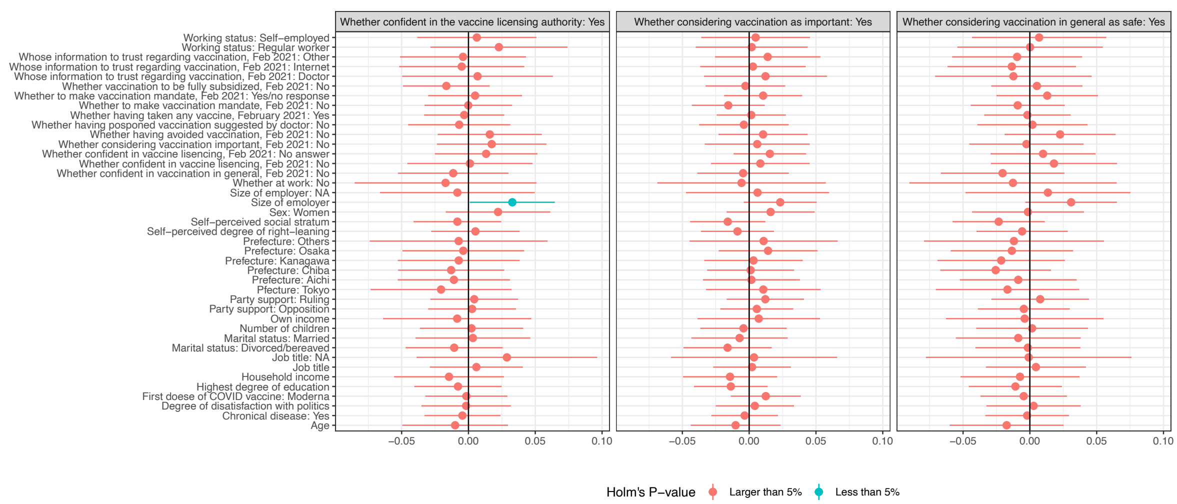

Figure A4: Impacts of "COVID arm" symptoms on confidence in vaccination: Best linear predictor.

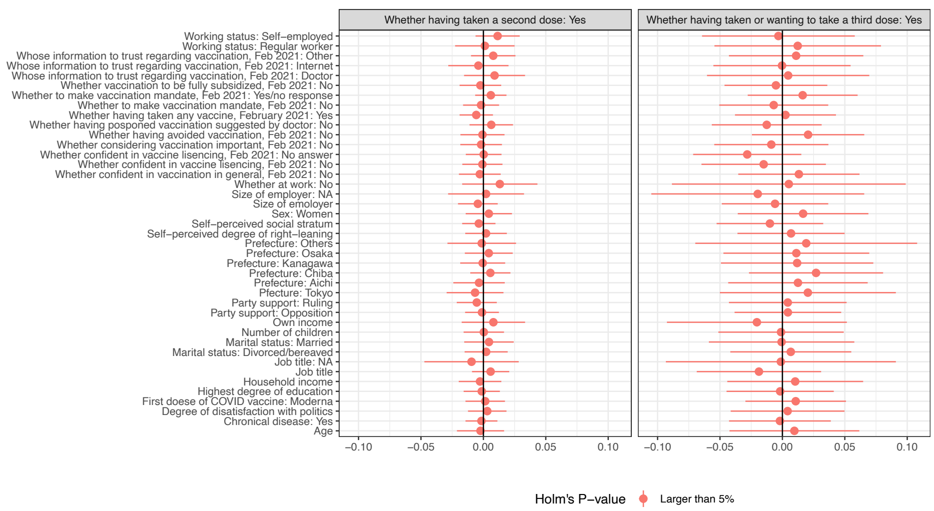

Figure A5: Impacts of "COVID arm" symptoms on the probability of taking a second dose and of taking or wanting to take a third dose: Best linear predictor.

Figure A6 presents the approximated average treatment effects on confidence in science in general, conditional on background characteristics $\boldsymbol{X}_i$. They are estimated by the best linear predictor, $E[\tau(\boldsymbol{x})|\boldsymbol{X}_i = \boldsymbol{x}] \approx \beta_0 + \boldsymbol{\beta} \times \boldsymbol{X}_i$. The predicted treatment effects of "COVID arm" symptoms on confidence in science in general were not significantly associated with background characteristics $\boldsymbol{X}_i$.

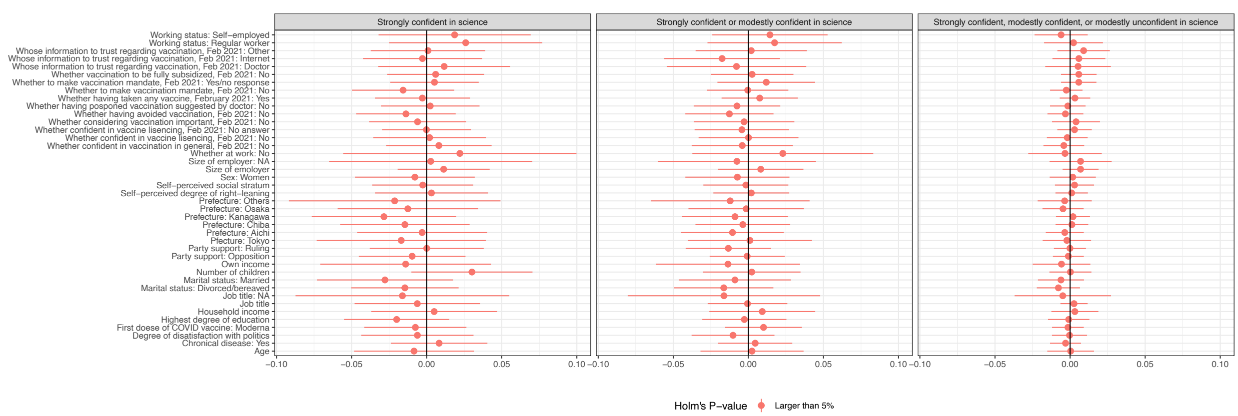

Figure A6: Impacts of "COVID arm" symptoms on confidence in science: Best linear predictor.